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Hans Hellmer.

In Memoriam

Swedish radiology has again suffered a severe blow. HANS HELLMER, Professor of Roentgendiagnostics at the University of Lund, died on 23rd of March, 1949, at the age of fifty. After an operation in September 1947

for a small cancer coli HELLMER soon resumed his work with undiminished energy. Nine months later, however, there appeared disquieting symptoms of liver metastases to which he succumbed about eighteen months after the operation.

Already at the age of 23 years HELLMER began to specialize in roentgen-diagnostics and was the first Swedish radiologist to pursue a career dedicated exclusively to this branch of radiology. His conception of the possibilities and limitations of roentgen-diagnostics was founded on the ideas he had received from his great teacher, Gösta Forssell. The careful correlation of normal anatomy and roentgen anatomy was his guiding star, which among other things directed his interest towards the instruction of the students in elementary roentgen anatomy. From this basic conception he looked upon roentgen-diagnostics as morbid anatomy in vivo and never missed an opportunity of comparing in detail operation or autopsy findings with roentgen findings.

In 1925 his name appeared for the first time in literature, when he published »Étude sur la muqueuse gastro-intestinale après gastro-entéro-anastomose». This work was followed by an even stream of publications on different roentgen diagnostic problems. His favourite field of research was roentgen-diagnostics of the urinary tract, and the results of his work on the technique and tactics of excretory urography were fundamental. During the last few years of his life, studies on intussusception in children caught his interest and during his fatal illness he terminated his monograph »Intussusception in Children» which will undoubtedly be a standard work on the subject. In his research work he always aimed at producing results of practical value and in his untiring endeavour even in every-day routine work to obtain the best possible results in every respect he created an invaluable material for clinico-roentgenologic research and at the same time assured both his colleagues and patients of the best roentgenologic aid available.

He realized the necessity of proper training for the students and acted accordingly. In spite of the enormous development of roentgenology during the last twenty-five years, the curriculum in Sweden still provides for only 20 lectures on roentgen-diagnostics. HELLMER realized the shortcomings of the system and by agreement with the students extended the scope of the instruction to include the daily presence of his pupils at actual examinations and the discussion of the diagnoses and differential diagnoses. In this manner he paved the way for a more thorough and stimulating education in roentgen-diagnostics worthy of the key position of this subject.

In spite of a short clinical training HELLMER had an exceptionally good talent of correlating roentgen diagnostic findings with clinical findings and was thus able to apply these diagnostical methods in a ma-

ner which, when backed by his skill and circumspect, may be considered the acme of proficiency. His portrayal of a disease was richly facetted, and his practical activity bore living witness to the inevitable requirement that roentgen-diagnostics be represented as an independent branch of medicine.

HELLMER's activity may be characterized by two words: ardour and veracity. He lived heart and soul for roentgen-diagnostics, to which he gave himself up entirely. Those values he created by his research work, by his teaching, and by his organization of the Roentgendiagnostic Department of Lund, all in the course of a relatively short life, were not to be bought without personal sacrifice. In early years HELLMER sustained a roentgen-ray lesion of the hands — at first probably the result of an accident — and on account of subsequent severe pains and the development of cancerous ulcerations, he was obliged to have most of his fingers amputated.

His love of truth left its mark on all his activity and is also reflected in his publications, in which a strictly logic formulation and keen self criticism bridled and sifted his manifold observations. It was also for this reason that his words, both spoken and written, carried weight and authority.

HELLMER was an austere man of few words, exigent in the clinic, but modest in private life. His keen judgement was never blurred by pettiness or irrelevancies but always based dispassionately on facts alone. This characteristic of his commanded respect, and as he himself respected the convictions of others, he was able to make many a lifelong friend.

HELLMER's personality comprised many an imposing trait. Most impressing, however, was his greatness of character during the last months of his life. Those friends of his whose steps directed them to his bedside to bid him farewell will for the rest of their lives remember the picture of a great man, of a man who had to the very utmost always tried to satisfy his own conscience, and who could therefore meet death without fear.

Olle Olsson.

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FROM THE I. ROENTGENDIAGNOSTIC DEPARTMENT OF SÖDERSJUKHUSET, STOCKHOLM, SWEDEN (CHIEF: DOCENT G. JÖNSSON)

THORACIC AORTOGRAPHY BY MEANS OF A CANNULA INSERTED PERCUTANEOUSLY INTO THE COMMON CAROTID ARTERY[1]

by

Gunnar Jönsson

When it is desired to visualize the chambers of the heart and the large vessels with the aid of contrast medium, the method of ROBB and STEINBERG is generally used without any modification. CHAVEZ, DORBECKER and CELIS are the only ones who have departed from the original technique but, judging from the description of their method, it, too, is rigidly standardized. Experience teaches the roentgenologist, however, that the procedure must be varied to fit the individual case, at least where adults are concerned. When it is wanted to study the entire circulation through the large vessels and all the chambers of the heart, the contrast medium should be injected in a cubital vein according to ROBB and STEINBERG, or through a catheter inserted through a peripheral vein and lying with its tip in the vena cava superior. The contrast agent is injected in the same way for study of malformations in the right auricle. For examination of the right ventricle, however, it is important to place the tip of the catheter in the ventricle itself. Otherwise the contrast fluid will be diluted on the way there and the picture of the dye-filled right auricle will be imposed on the picture of the ventricle, obscuring the details. When the pulmonary artery or the left auricle and ventricle are to be examined it may be advantageous to insert the contrast medium by means of a catheter into the pulmonary artery. A more detailed account of this varying and individual technique will be published later.

Modern surgery requires a minute and careful examination of the aorta. This is not possible in adults unless the contrast medium is injected directly into the vessel (BRODÉN, HANSON, KARNELL, GROSS). Coarctation can be diagnosed in children with the angiocardiographic method

[1] Read at the Meeting of the Swedish Association for Medical Radiology, Febr. 25, 1949; submitted for publication, March 3, 1949.

o ROBB and STEINBERG, b t a patent ductus cannot b studied with any degree o certainty either in chil- d en or adults without di- r ct aortography. In 1947 w devised a technique for th oracic aortography based o RADNER's work with ar- terial catheterization. The technique was described by BRODÉN, HANSON and KAR- NELL in this journal in the beginning of 1948. Briefly, it is as follows. After dissec- tion of the radial artery under local anesthesia, a heart catheter (8—10 F) is inserted into the vessel. The catheter is guided to the aorta under fluoroscopic control. When it has reached there, 50 to 70 cc. of a 70 per cent solution of iodo- pyracet (diodrast, umbradil) are injected as rapidly as possible. Since this report, the technique has been changed in one important respect. Instead of doing the injection by hand, we now use a specially constructed pressure apparatus which enables more rapid injection of the dye (fig. 1).

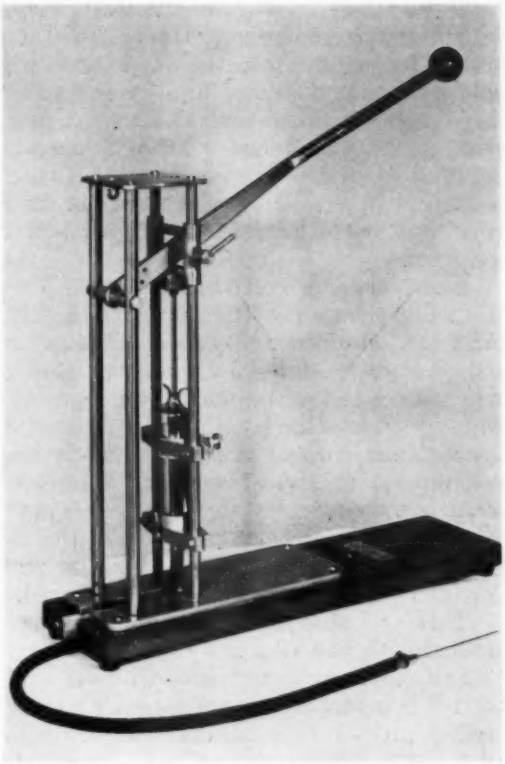

Fig. 1. The pressure apparatus.

As a rule it takes about three seconds to inject the dye, the result being a dense shadow of the aorta and distinct pictures.

Experience has proven, however, that this method has a number of drawbacks. It is complicated and takes a great deal of time. In many cases the radial artery has to be sacrificed. Even if it is sutured, it often becomes obliterated. There is an extensive collateral system, of course, but it goes against the grain to destroy an artery unless it is absolutely unavoidable. Another disadvantage of the method is that it is some- t mes impossible to introduce the catheter in the aorta because of angio- spasm. Spasmolytics and other drugs with a dilating effect seldom, if ever, succeed in doing away with this form of spasm.

It was clear to us from the start, therefore, that it would be better with a simpler technique. On analysis of the different anatomic possibilities for coming into the aortic arch with catheters or cannulas, the only route which seemed to offer any advantages over the one used was through the common carotid artery. Using an artery of this rank, however, required a method which contained no risk of permanent damage.

In a review of angiography of 1946, BLAKEMORE mentioned the possibility of visualizing the aorta via the right common carotid artery. How this operation was performed, however, is not clear from his description.

FREEMAN and STEPHENS described a method of retrograde injection of diodrast into the left common carotid artery. Using this method, FREEMAN obtained satisfactory visualization in 14 out of 18 cases. The artery is exposed by a transverse incision above the sternoclavicular articulation and surrounded by a segment of rubber tubing. After preliminary roentgenograms the distal carotid is compressed and a needle inserted under direct vision into the lumen of the artery. A 70 per cent iodopyracet (diodrast) solution is injected as rapidly as possible and serial roentgenograms are taken. The authors stress the importance of occluding the carotid artery above the needle during the injection so that none of the iodopyracet solution reaches the cerebral circulation. Convulsions may otherwise be produced.

This procedure does not seem to have any advantages over our method with insertion of a catheter through the radial artery.

Long and large experience with cerebral angiography has shown that no risk is incurred by percutaneous puncture of the carotid artery with needles with an external diameter of up to 1.5 mm. (MONIZ, WICKBOM, SIMONSEN). There seems to be no reason why a similar procedure should not be used for filling the thoracic aorta with contrast medium. But this involves a number of special technical problems. It is not enough to insert a needle a few millimeters into the carotid artery and then inject the medium. It might be possible, of course, to press the contrast solution down into the aorta by making the injection under high pressure. The chances are, however, that the solution would be too diluted when it reached there and most of it would go to the cerebral vessels. This would be a poor method from the point of view of aortography. Moreover, it would involve a risk of cerebral injury. In order to get a satisfactory concentration of the dye in the aorta, the cannula must be inserted so far down that its tip lies in the lumen of the aorta. It would be impossible without special measures to use an ordinary pointed puncturing needle for this. A needle of this kind would injure the walls of the carotid or innominate artery on the way down. In fact, probably it would never get down to the aorta, but perforate the vascular wall and end up

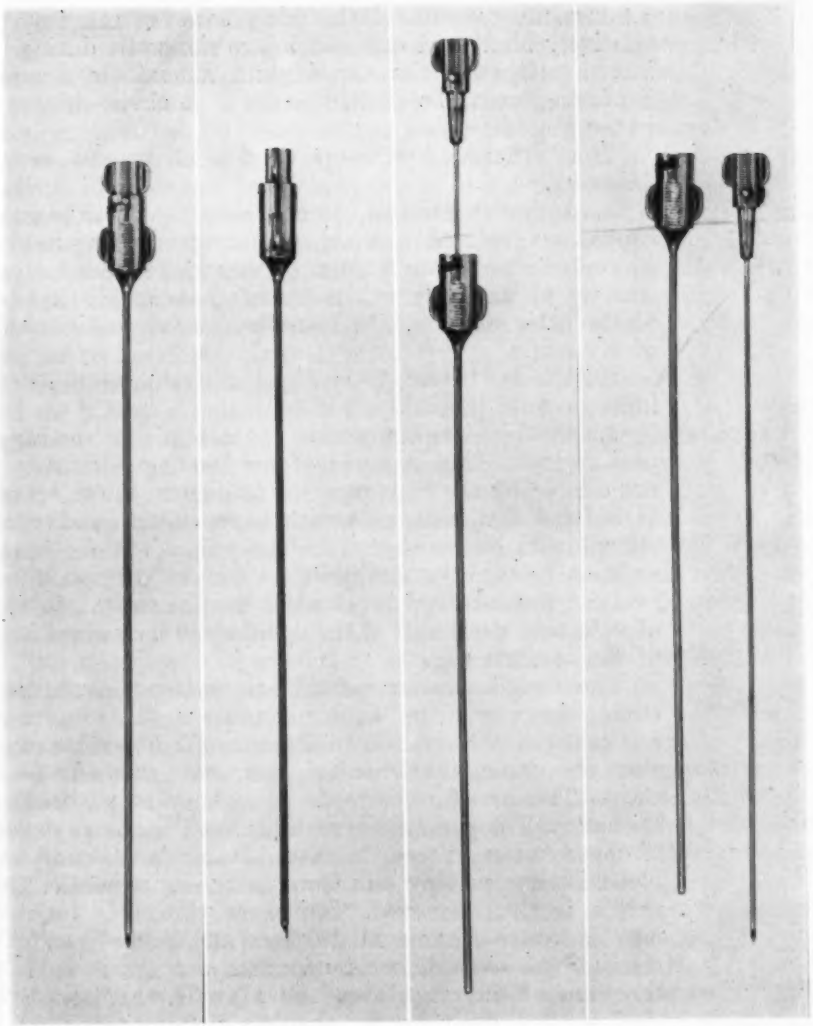

Fig. 2. The double cannula, 13 cm. long. The external diameter is 1.5 mm.

in the perivascular tissue instead. Accordingly, it is necessary to use a blunt cannula. However, in order not to make too large a puncture opening in the artery and incur the risk of permanent damage there, the cannula must be fairly slender. Its external diameter should not exceed

Fig. 3. A silver thread, 28 cm. long, inserted into the outer cannula.

1.5 mm. A cannula of this bore, however, can only be relatively blunt and can still injure the walls during its insertion through the carotid and innominate arteries. Something must be done, therefore, to obviate this risk in the procedure.

The technical equipment we use at present is the following.

1. A double cannula, 13 cm. long (fig. 2). The inner cannula is pointed like an ordinary puncturing needle. The outer cannula has a blunt opening with rounded edges. The tip of the inner needle reaches just outside the edge of the outer cannula. The latter has an external diameter of 1.5 mm.

2. A silver thread, 28 cm. long, the same width as the inner cannula (fig. 3).

3. A tubing for connecting the cannula to the injection syringe. This is made of hard rubber so that it is not dilated by the high pressure arising on the injection. It is fixed to the cannula with bayonet locks and to the syringe with screws (fig. 1).

4. A metal injection syringe.

5. A pressure apparatus which enables rapid injection of sufficient quantities of the dye despite the narrow bore of the cannula (fig. 1).

The right common carotid artery is punctured percutaneously with the double cannula in the same way as described for cerebral angiography (WICKBOM), except that the cannula is directed downward instead of upward. The puncture is made as high up as possible on the artery. The patient lies with his head in a large degree of dorsal flexion. When the cannula comes into the artery, blood is seen passing out through the inner needle. The needle is then removed. The silver thread is inserted into the outer cannula in its place and pushed carefully through the carotid and innominate arteries down into the aorta. Using the thread as a guide, the cannula is then pushed down so far that its tip comes inside the aortic arch. When a guide of this kind is used, there is no risk of injury to the arterial wall. The thread is very soft and has a rounded tip, and it cannot do any damage if it is pushed down slowly and gently. In order to avoid blood clotting in the cannulas, the latter are irrigated with saline solution throughout the procedure. The silver thread is also moistened with heparin.

The most uncertain point in the whole procedure lies in judging how far down to push the cannula for its tip to enter into the aortic arch — and it is important that this happens. If the tip lies up in the innominate artery, there will be a strong backflow of the dye and a risk of cerebral reaction. If it lies far down in the aorta, the pulsatory movements of the vessel may cause it to injure the walls. We tried to determine the position of the cannula by inserting it under fluoroscopic control, but this did not prove a satisfactory method. It is essential that everything be done as quickly as possible and, furthermore, it is unpleasant to carry out a serious manipulation of this kind in the dark. However, if the position of the aortic arch is determined with fluoroscopy and marked on the thoracic wall before the puncture, it is fairly easy to calculate how far to insert the cannula.

When the cannula has been inserted, the silver leader is removed and the tubing is connected to the cannula. With the aid of the pressure apparatus 40 to 80 cc. of contrast solution are injected in about three seconds. A 70 per cent solution was used in most cases but, as will be seen later, a 50 per cent solution should be employed.

Serial roentgenograms are taken during the injection, six to ten pairs of pictures in two perpendicular planes as described by BRODÉN, HANSON and KARNELL. As soon as the injection is made, the cannula is removed. The site of puncture is compressed for a while by hand to prevent the development of large hematomas. The operation is then concluded.

We have used this method of aortographic examination in 10 cases. In 8 of them we obtained distinct pictures of the aorta ascendens, aortic arch and thoracic aorta (fig. 4 and 5). In one case it was impossible to carry out the examination because of malformation of the carotid artery (later visualized with angiocardiography). As regards the remaining case, while it was easy to insert the cannula down into the aorta, scoliosis and deformity of the thorax caused it to slant too much to the left. The result was that the stream of contrast went directly into the thoracic aorta, and the aorta ascendens and arch were not visualized.

Complications are possible either as a result of the mechanical intervention or due to the toxic influence of the contrast medium.

As mentioned before, the extensive literature on cerebral angiography contains no mention of serious complications after puncture of the carotid artery. Naturally there has not been the same experience with the insertion of a straight inflexible cannula through the carotid and innominate arteries. Using the method described in this paper, it seems very unlikely that the cannula would do any damage on its way through the vessels. On the other hand, it is conceivable that the tip of the cannula comes to rest against the inner wall of the aorta and that the pulsatory

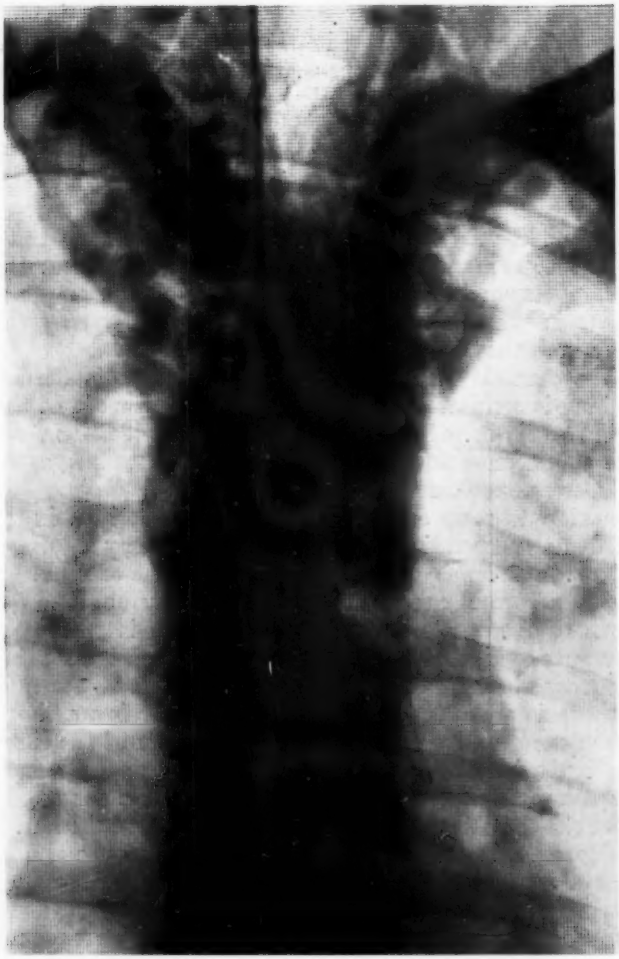

Fig. 4 a.

Fig. 4. Coarctation of the aorta. Frontal view,

movements cause it to injure the wall. However, it is hardly likely that this would cause any serious damage. Making the puncture too far down, which must be regarded as a technical error, involves a risk of injury to the pleura.

The possibility of the contrast medium hurting the endothelium in

Fig. 4 b.

before (a) and after (b) operation.

the heart and vessels has been envisaged from the first roentgenographic studies of the heart with contrast medium. BROMAN and OLSSON showed in their experimental investigation that this happens in the cerebral vessels of rabbits even when fairly weak concentrations are used. Our patients are given penicillin and heparin prophylactically to prevent

Fig. 5 a. Fig. 5 b.

Fig. 5. The same case as in fig. 4. Lateral view, before (a) and after (b) operation.

infection and thrombosis. Clinical signs of damage to the heart or great vessels have never been observed. Nor did the autopsy of three patients who died two or three months after the aortographic examination reveal any signs of pathologic change conceivably attributable to the contrast medium. On the other hand, one of our patients reacted with cerebral symptoms. In this case we used a new contrast agent which turned out

to be more toxic than diodrast and umbradil. Other investigators have also found it to be too toxic. The patient reacted immediately with severe convulsions and lay unconscious for three days before she recovered. After that we changed from a 70 to a 50 per cent solution of the medium. This concentration has proved to be sufficient.

Indications. This method constitutes a simplification of our aortographic technique. Nevertheless it is by no means an easy method. Moreover, it offers but small possibility of variation and can therefore not be used as a standard method.

It should not be used in cases of patent ductus. It is true that it is just as easy with it as with the catheter method to establish the existence of a shunt between the aorta and the pulmonary artery. But when it is necessary to differentiate between a patent ductus and a shunt in the region of the sinus of Valsalva, the most important task of roentgenographic examination, it is necessary to inject the contrast fluid through a catheter inserted through the radial artery far enough for its tip to reach the lower part of the ascendent aorta.

It should not be used when there is reason to suspect morbid changes in the innominate or carotid artery, or when there are plans of surgical intervention in the upper right part of the mediastinum. The hematomas easily developing on puncture may descend down along the vessels and cause difficulties for the surgeon.

It seems to be the best method for the examination of malformations in the aortic arch and thoracic descendent aorta. This is especially true of coarctation of the aorta. In this disease the carotid artery is wide and the pulsations are powerful, making puncture of the artery relatively easy. In order to get the best visualization of the aortic arch, the contrast medium should flow into the aorta directly below the origin of the innominate artery, and this happens when the present method is used. When coarctation is present, more blood than normally passes through the cerebral vessels, and there is a relatively large risk of brain injury. Iodopyracet should be used in a 50 per cent solution at the most. A 70 per cent solution is dangerous.

SUMMARY

The common carotid artery is punctured percutaneously with a double cannula composed of an inner needle with a sharp point and a blunt outer cannula. After the puncture the needle is removed and the cannula inserted down into the aorta using a silver thread as a guide. Then 40 to 80 cc. of an iodopyracet solution are injected in about three seconds with the aid of a pressure apparatus. No more than a 50 per cent solution should be used in order to avoid cerebral complications.

ZUSAMMENFASSUNG

Die A. carotis communis wird perkutan punktiert mittels einer Doppelkanüle, die aus einer inneren Nadel mit scharfer Spitze und einer stumpfen äusseren Kanüle besteht. Nach der Punktion wird die Nadel entfernt und die Kanüle in die Aorta hinab vorgeschoben, wobei ein Silberdraht als Führer verwendet wird. Dann werden im Laufe von etwa drei Sekunden mit Hilfe eines Druckapparates 40—80 ccm einer Jodopyrazetlösung eingespritzt. Es darf zur Vermeidung von Gehirnkomplikationen nicht mehr als 50%ige Lösung Verwendung finden.

RÉSUMÉ

La carotide primitive est ponctionnée au travers de la peau avec une canule double composée d'une aiguille intérieure pointue et d'une canule extérieure mousse. Après la ponction on enlève l'aiguille et la canule pousse vers le bas dans l'aorte en se servant d'un fil d'argent comme guide. Ensuite 40 à 80 cc. d'une solution iodopyracétique sont injectés en trois secondes environ, à l'aide d'un appareil à pression. On ne doit pas se servir d'une solution dont la concentration dépasse 50 % si l'on veut éviter des complications cérébrales.

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AUS DEM PATHOLOGISCHEN INSTITUT DER UNIVERSITÄT, GENF, SCHWEIZ
(DIREKTOR: PROF. DR. E. RUTISHAUSER)

WIRBELRAHMENEINZIEHUNGEN[1]

ZUR FRAGE DER KNOCHENPLASTIZITÄT

von

Hugo Tschumi

Wir hatten am Genfer pathologischen Institut Gelegenheit, zwei Fälle mit starken Wirbelrahmeneinziehungen zu studieren. Es handelte sich um eine senile Osteoporose und eine pathologisch komplexe Osteopathie bei Morphinomanie.

Die Röntgenbilder der beiden Wirbelpräparate zeigen eine starke Abplattung der Wirbel (Brachyspondylie[2]) mit deutlichen Einknickungen der Wirbelrahmen ohne radiologische Verdichtung (Kallus) der Knochenstruktur, vgl. Fig. 1 und 7.

Wir versuchen, durch die histologische Untersuchung der betreffenden Wirbel zu erklären,

1) in was der zu diesem Resultat führende Prozess besteht: Fraktur oder Plastizität.
2) wie auf Grund unserer heutigen Kenntnisse die Knochenplastizität zu verstehen ist.

Histologische Beschreibung unserer Fälle

1. Fall: Autopsie Protokoll 235/45.

77-jährige Frau. Die Untersuchung des Skeletts ergibt: Die Konsistenz des Knochens ist überall stark vermindert. Der latero-laterale Thoraxdurchmesser ist verkürzt, der antero-posteriore dagegen verlängert. Man sieht viele Kallusbildungen an den Rippen, welche von Spontanfrakturen herrühren. An der Wirbelsäule fallen die stark abgeflachten

[1] Bei der Red. am 15. III. 1949 eingegangen.

[2] ROST schlägt vor, den Begriff *Platyspondylie* für die Breitwirbel im Sinne PUTTIS zu reservieren; und für die übrigen Formen von abgeflachten Wirbeln, deren Hauptmerkmal die Verkürzung ist, den lateinischen Namen Vertebra brevis zu verwenden. In Analogie zu Platyspondylie schlagen wir daher den Namen *Brachyspondylie* vor (brachys= kurz), wie er schon im Namen Platybrachyspondylie von GUERIN und LACHAPELE gebraucht wird.

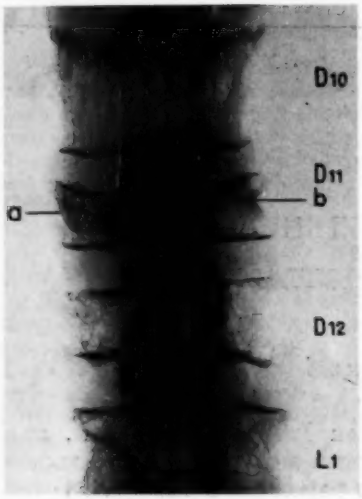

Fig. 1 a. Röntgenaufnahme von Fall I.

Starke Osteoporose mit schmalen und weit auseinanderliegenden Knochenbälkchen und starker Verkalkung der Wirbelabschlussplatten. Verkalkung der Gallertkerne.

Der elfte und zwölfte Dorsalwirbel zeigen hochgradige Verkürzung ihres Längendurchmessers mit Verdichtung der Trabekelstruktur. D 11 zeigt bei a die in Fig. 2 dargestellte bogenförmige Einziehung und bei b die in Fig. 3 wiedergegebene spitzwinklige Einziehung.

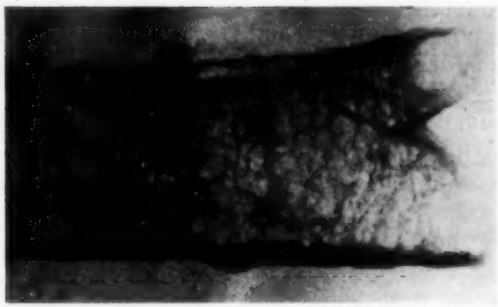

Fig. 1 b. Ausschnittvergrösserung der Einziehung (b) bei D 11.

Zwischenwirbelscheiben und 4 ebenfalls abgeflachte Wirbel auf. Das Knochenmark ist rot und feucht.

Der von uns untersuchte Wirbelsäulenabschnitt umfasst die Wirbel D 10—11—12—L 1.

In den Wirbelkörpern sieht man mikroskopisch hauptsächlich das Bild einer hochgradigen Osteoporose. Die Trabekel sind dünn und weit auseinander stehend und haben nur sehr spärliche Querverstrebungen. Bei den abgeflachten Wirbeln zählt man ungefähr die doppelte Anzahl Trabekel, als in den anliegenden Wirbeln von normaler Höhe. Die Trabekel sind im grossen und ganzen wenig umgebaut; man findet fast keine mikroosteonekrotische Herde. Dagegen sieht man einige Trabekel mit schmalen osteoiden Säumen. Das Knochenmark ist gemischtzellig mit vereinzelten Lymphfollikeln; in den

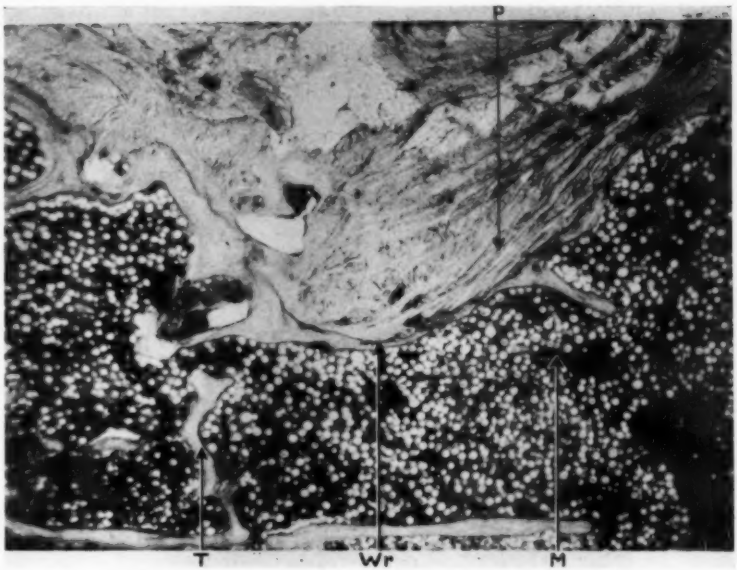

Fig. 2. Fall I.

Bogenförmige Einbiegung des Wirbelrahmens.

Wr = Wirbelrahmen. T = Knochentrabekel.
P = Periost. M = Knochenmark.

abgeflachten Wirbeln sieht man einige sogenannte Lipombildungen ohne Gefässproliferation. Die Wirbelabschlussplatte ist sehr dünn; an verschiedenen Orten sogar vollständig verschwunden, sodass das Knochenmark direkt an den Faserknorpel grenzt. Es bestehen keine Diskushernien, weder ins Innere des Wirbelkörpers (Schmorl'sche Knötchen) noch lateral.

Der Wirbelrahmen ist bei allen Wirbeln ebenfalls sehr dünn, ungefähr von gleicher Dicke wie die Trabekel. Stellenweise ist er unterbrochen, sodass auch hier das Knochenmark an das Periost grenzt. Bei den abgeflachten Wirbeln ist der Wirbelrahmen der Sitz charakteristischer Veränderungen: zum Teil Verstärkung der natürlichen Krümmung mit Konkavität nach aussen (vgl. Fig. 2), zum Teil eigentliche Angulationen (vgl. Fig. 3—6 und Fig. 8), indem der Wirbelrahmen einen nach aussen offenen Winkel bildet. Das Periost folgt der Verformung des Wirbelrahmens und bei stärkster Abflachung können sich die Periostschichten der beiden Schenkel zu einem einzigen Bindegewebsstreifen vereinigen, welcher stellenweise hyaline oder basophile Umwandlung oder seltener sekundäre Verkalkungsherde aufweist.

Die Wirbelrahmenschenkel zeigen Spuren eines intensiven, noch nicht abgeschlossenen Umbaus. Die mittleren leicht gebogenen Partien weisen keine Zeichen alter Veränderungen auf, sondern befinden sich noch im vollen Anfangsstadium der biologischen Strukturänderung, welche in einer *Resorption auf der äussern und einer Apposition auf der inneren*

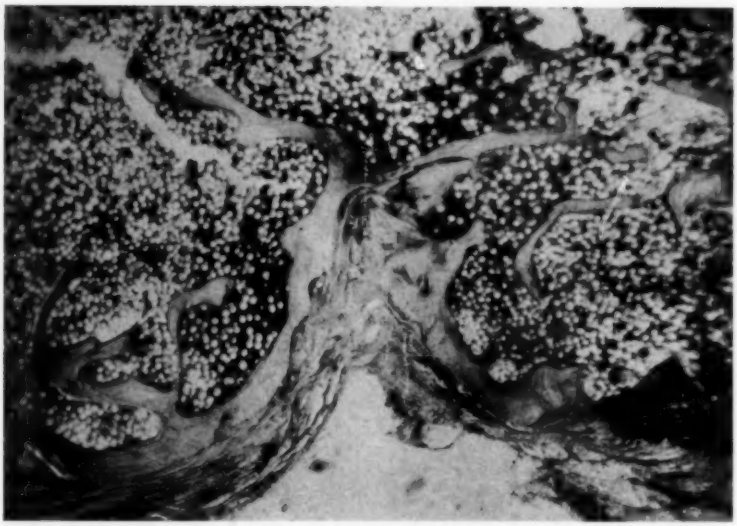

Fig. 3. Fall I.

Spitzwinklige Einziehung des Wirbelrahmens mit nach aussen offenem Winkel. In der Tiefe des Winkels wurden die Schenkel durch das Zusammensinken des Wirbels einander so stark genähert, dass die beiden Periostschichten verschmolzen sind. Weder Corticalishypertrophie noch Spongiosasklerose.

Seite besteht. Der Umbau vollzieht sich parallel der Richtung der Knochenlamellen. Aus den Abbildungen ist ersichtlich, dass der Wirbelrahmen dort am stärksten umgebaut wird, wo die Krümmungen am ausgesprochensten sind. Auf keinem unserer Schnitte konnten wir Spuren einer Fraktur oder von Infraktionen des Wirbelrahmens feststellen.

2. Fall: Autopsie Protokoll 181/45.

70-jähriger Mann. Seit 30 Jahren morphino- und kokainoman (bis 2.0 g Mo im Tag). Das Skelett weist eine Brachyspondylie durch atrophierende Osteopathie bei Toxicomanie auf. In unserem Präparat der Lendenwirbelsäule finden wir Verbiegungen und Angulationen des Wirbelrahmens. Durch die sehr weitgehende Atrophie des Knochens wird der Befund jedoch weniger charakteristisch für die Knochenplastizität. Der Rahmen besteht in der ganzen Wirbelhöhe eigentlich nur aus einer randständigen Verdichtung der Knochenbälkchen, welche unter sich verbunden zu sein scheinen. An der Stelle der Angulation besteht nicht einmal mehr eine Kontinuität zwischen den Trabekeln, und die Wirbelrahmeneinziehung ist nur erkenntlich an den periostalen Bindegewebszügen, welche auf dem Schnitt ein nach aussen offenes »V» bilden. Das Periost ist stellenweise verbreitert und verkalkt. Der Raum zwischen den beiden Schenkeln ist von faserigem, zum Teil metaplastisch verknöchertem Bindegewebe ausgefüllt. Die unter der Periostschicht befindlichen Trabekel scheinen durch die Stauchung relativ vermehrt; in diesem Gebiet sehen wir auch ziemlich ausgedehnte Herde metaplastischer Ossifikation. Die

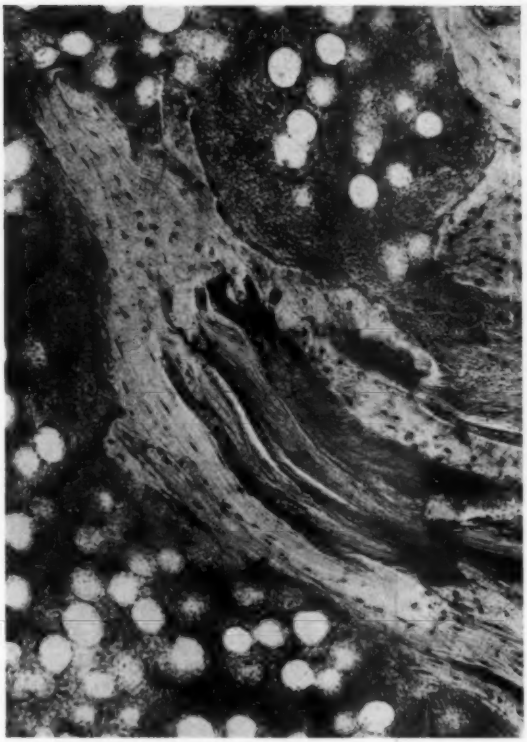

Fig. 4. Fall I (Thionin-Färbung).

Spitze der Einziehung bei stärkerer Vergrösserung. Der Wirbelrahmen, bestehend aus einigen wenigen Lamellen, bildet eine in das Mark hineinragende Schlaufe und schliesst in seinem Innern die beiden verschmolzenen Periostblätter ein. Auch hier fällt die Dünnheit der Corticalis auf. An der Abwinkelungsstelle und im unteren Schenkel sehen wir Spuren vom Umbau.

Trabekel sind von lamellärer Struktur, welche von zahlreichen Abbaukittlinien durchbrochen wird. Die Osteozyten sind nur ausnahmsweise onkotisch.

Wie im ersten Fall entspricht auch hier das Gesamtbild keineswegs einem Kallus nach Fraktur oder Infraktion.

Das histologische Bild der hochgradigen Formveränderungen in unseren beiden Fällen lässt sich weder durch Fraktur noch Infraktion erklären. Wir müssen deshalb einen andern Vorgang in Betracht ziehen: die Knochenplastizität.

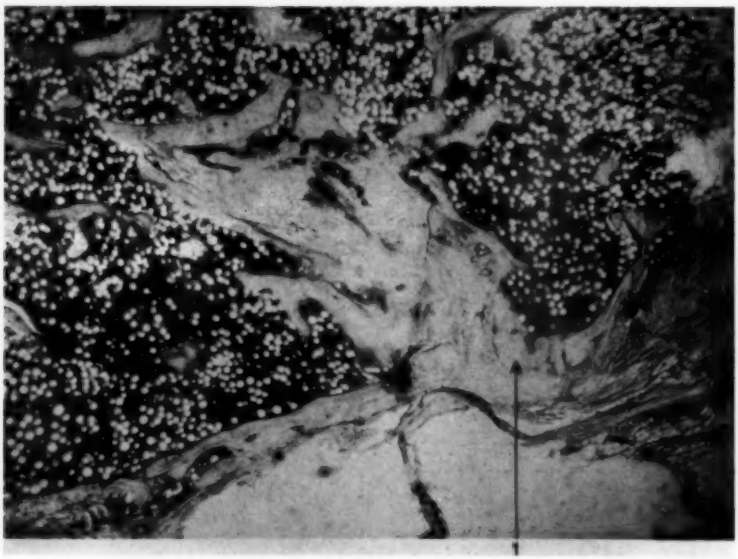

Fig. 5. Fall I.

Extreme Angulation mit Verschmelzung der beiden Schenkel. Das Periost der Wirbeloberfläche hat seine Kontinuität wieder hergestellt, so dass die Invagination als isoliertes Gebilde im Innern des Wirbelkörpers imponiert. Sie besteht aus bindegewebigen Periostfasern, eingeschlossen in einer unterbrochenen Knochenschale, als Überrest des alten Wirbelrahmens.

(Bei 1 die in Fig. 6 vergrössert abgebildete Stelle.)

Auf Grund des Vergleiches mit plastischen Metallen, wo die Plastizität durch Veränderungen im Kristallgefüge bedingt ist, wurde besonders von HENSCHEN die Auffassung vertreten, dass die Plastizität des Knochens auf einer Verformbarkeit der Kristalle der anorganischen Knochensubstanz bestehe. Die Untersuchungen von BRANDENBERGER und SCHINZ auf röntgenspektroskopischem Wege und von DALLEMAGNE auf chemischem Wege zeigen aber, dass die Salze der anorganischen Knochensubstanz — Phosphat und Karbonat — in ihrer komplizierten, physikalisch komplex gebundenen Form, dem Hydroxylapatit, ein äusserst starres Kristallgefüge bilden, welches keinerlei Fähigkeiten zur Gleitung und Schiebung der einzelnen Kristallebenen unter sich besitzt. Somit muss man annehmen, dass eine gewisse Plastizität durch gegenseitige Verschiebung *zwischen* den Kristallen ermöglicht wird.

Wir dürfen jedoch den Knochen nicht nur vom physikalisch-mechanischen Standpunkt aus betrachten, da er ja ein lebendes Gewebe ist, sondern wir müssen auch die biologischen Faktoren berücksichtigen.

Wir wollen versuchen, die Rolle der beiden Faktoren — mechanischer = Plastizität und biologischer Faktor = Umbau — im mikroskopischen

Fig. 6. Fall I (Détail von Fig. 5).

Winkelförmige Abbiegung zwischen Schenkel der Einziehung und normal gerichtetem Wirbelrahmen. Diese Stelle ist durch verschiedene, durch Abbaukittlinien begrenzte Teile gebildet. Hier sieht man deutlich, dass die Verbiegung nicht durch einfache Krümmung einer ganzen Knochenlamelle zustande kam, sondern durch intensiven Gewebeumbau. Es befinden sich unter diesen Teilen möglicherweise noch solche, die aus der ursprünglichen Corticalisschicht stammen.

Bild darzustellen. Der mechanische Deformationsfaktor ist zweifellos vorhanden: er ist zwar schwer darzustellen, denn neben den plastischen Verformungen bestehen auch die reversiblen elastischen Veränderungen, welche unseren Untersuchungsmethoden natürlich entgehen. Er ist jedoch immer indirekt an seinen Folgen zu erkennen. Denn die mechanischen Kräfte spielen die Rolle des auslösenden Faktors für den biologischen Umbauprozess, welcher in der von ihnen vorgeschriebenen Richtung vor sich geht.

Wenn wir die in Fig. 3 abgebildete, bedeutende Angulation des Wirbelrahmens näher betrachten, so fällt uns auf, dass die Schenkel des Winkels, beide leicht gebogen, von lamellärem Knochen gebildet sind. Dieser scheint der gleichen Knochengeneration anzugehören, wie die nicht veränderten Wirbelrahmenteile. Es könnte sich also um die alte Kortikalis handeln, welche durch einfachen mechanischen Druck verbogen ist.

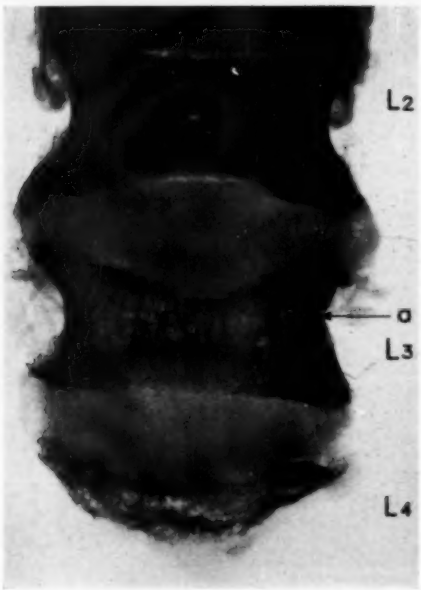

Fig. 7. Fall II.

Röntgenaufnahme. Osteopathie bei Toxicomanie. Bei a leichte Angulation des Wirbelrahmens.

Doch der mechanische Faktor ist hier nicht die einzige und besonders nicht die wichtigste Komponente: Wir sehen nämlich deutliche osteoklastische Vorgänge auf der äussern (periostalen) Seite der Knochenlamellen, und osteoide Apposition, bei hochgradiger Osteoporose!, auf der innern (endostalen) Seite. Dies zeigt eindeutig, dass der mechanischen Deformation der biologische Umbau auf dem Fusse folgt. *Die Osteoklasie auf der konvexen und die Apposition auf der konkaven Seite bewirken eine Verstärkung und hauptsächlich die Fixierung der Verbiegung.*

Wir kommen also zum Schlusse, dass die mechanische Deformation die biologischen Umbauvorgänge auslöst. Eine rein mechanische Verformung allein ist nicht dauerhaft, wenn sie nicht durch gewebliche Umwandlung, in unserem Falle durch Resorption und Apposition fixiert und stabilisiert wird. Unseres Erachtens spielen sich in diesen Knochenlamellen die gleichen Vorgänge im Kleinen ab, wie wir sie, auf das Organ ausgedehnt, bei einer Coxa vara oder Coxa valga oder bei einer Kyphoskoliose vorfinden. Man könnte sie infolgedessen als *Elementarläsion* dieser Affektionen bezeichnen.

Ausser in Bezug auf Knochenplastizität scheinen uns diese Fälle auch in anderer Hinsicht von Interesse zu sein. Die beschriebenen Läsionen können im Grunde auch als Überlastungsschäden betrachtet werden. Es handelt sich allerdings nicht um eine absolute, sondern relative Überlastung, indem die Widerstandskraft des Knochens herabgesetzt ist (quantitativ bei der Osteoporose und qualitativ bei der Osteopathie bei Morphinomanie).

In neuester Zeit haben RUTISHAUSER und MAJNO beim Hund experimentelle Überlastungsschäden erzeugt und gelangten auf Grund der histologischen Untersuchungen zu folgender Einteilung, in absteigender Reihenfolge: 1) sofortige Fraktur; 2) Dauerbruch; 3) pathologische Hyper-

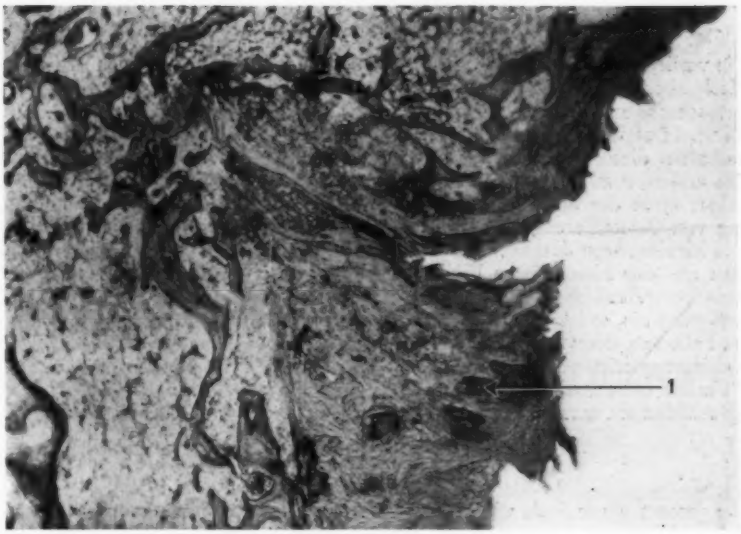

Fig. 8. Fall II.

Ähnliches Bild wie in Fig. 5.

Da der Wirbelrahmen extrem atrophisch ist und an verschiedenen Stellen Lücken aufweist, ist die Angulation am Verlauf des Periosts zu verfolgen. Man erkennt verschiedene subperiostale metaplastische Ossifikationsherde (1).

trophie mit Übergang in Umbauzone (Ersatz des Knochens durch dichtfaseriges Bindegewebe); 4) Arbeitshypertrophie.

In unseren Fällen, wo ein pathologisches Gewebe der Überlastung ausgesetzt war, haben wir nun Läsionen, wie sie im Schema von Rutishauser und Majno nicht vorgesehen sind: wir haben weder Fraktur noch Dauerbruch, sondern einfach *Deformation durch progressiven Knochenumbau ohne Hypertrophie.*

Was uns in dieser Hinsicht besonders erwähnenswert scheint, ist die Tatsache, dass die Überlastung Veränderungen hervorzubringen vermochte, die mikroskopisch als einfache plastische Deformationen imponieren. Das Knochengewebe reagiert auf die Überlastung durch Veränderung seiner Form, gemäss den wirkenden mechanischen Kräften, aber ohne eine Hypertrophie zu entwickeln. Wir kommen somit zur Annahme, ohne auf das Problem im einzelnen eintreten zu wollen, dass die Überlastung von pathologischem Knochengewebe zu anderen Veränderungen führt, als die Überlastung von normalem Knochengewebe.

ZUSAMMENFASSUNG

Die vorliegende Arbeit behandelt die Knochenplastizität in feingeweblicher Hinsicht. Der Mechanismus dieser Plastizität am Wirbelrahmen von Flachwirbeln in einem Falle von Osteoporose und in einem Falle von Osteopathie durch Toxicomanie wird untersucht.

Es wird festgestellt, dass die Belastung zu gross war im Verhältnis zu den statischen Eigenschaften dieser pathologischen Knochengewebe, von denen das eine quantitativ und das andere sowohl quantitativ als auch qualitativ vermindert ist. Die Folgen sind erkennbar: a) in der Spongiosa, wo die Trabekel näher zusammengerückt sind, ohne Bildung von Osteosklerose; b) im Wirbelrahmen, welcher Verbiegungen und zum Teil multiple Einziehungen durchgemacht hat, ohne zu hypertrophieren. Physikalische Überlegungen und das histologische Bild erlauben, einen Verbiegungsmechanismus auf rein mechanisch-physikalischer Grundlage auszuschliessen. *Der mechanische Faktor leitet die Verbiegung ein, welche durch den Knochenumbau fortlaufend stabilisiert wird.*

Im Falle von Osteoporose und von gemischter Osteopathie durch Toxicomanie führt der Überlastungsschaden zu besonderen Veränderungen: Plastische Knochendeformation durch Umbau ohne Fraktur und ohne Hypertrophie; Veränderungen, welche bei Überlastungsschäden am normalen Knochengewebe nicht beobachtet werden.

SUMMARY

The present paper deals with plasticity of bones giving special consideration to the microscopical findings. The mechanism concerned in producing plasticity of the vertebral cortex in a case of osteoporosis and in a case of osteopathia caused by toxicomania is studied.

It was found that the charging was too much increased relative to the static properties of these pathological osseous tissues, one being quantitatively and the other quantitatively as well as qualitatively reduced. The sequelae are recognizable: a) in the spongiosa, where the trabeculæ are lying closer to each other, osteosclerosis being absent; b) in the vertebral cortex which exhibits bending, and partly multiple foldings. There is no evidence of hypertrophy. On the basis of the mechanical resistance and of the histological findings the possibility can be precluded that mechanical factors alone are involved in producing bending of the bone. *The mechanical factor initiates the process of bending which is progressively stabilized by transformation.*

In osteoporosis and osteopathia caused by toxicomania special lesions are produced by overstrain: *i. e.* plastic deformation by transformation of the bone tissue without fracture nor hypertrophy; changes which are not met with in overstrain-lesions of normal bone tissue.

RÉSUMÉ

Ce travail traite de la plasticité osseuse au point de vue de l'anatomie microscopique. Le mécanisme de cette plasticité a été étudié sur le cadre vertébral de vertèbres plates dans un cas d'ostéoporose et dans un cas d'ostéopathie par toxicomanie.

On constate que la charge supportée a été trop grande par rapport aux capacités statiques de ces tissus osseux pathologiques, dont l'un est déficient quantitativement, et l'autre aussi bien quantitativement que qualitativement. Les conséquences en sont manifestes: a) dans la spongieuse, où les trabécules se sont tassées, sans production d'ostéosclérose; b) dans le cadre vertébral qui a été le siège de courbures et en partie de rétractions sans présenter d'hypertrophie. Des considérations de résistance mécanique et l'image histologique permettent d'exclure un mécanisme de déformation à bas

urement physico-mécanique. Le *facteur mécanique amorce la déformation, qui est stabilisée de façon continue par le remaniement osseux.*

Dans le cas d'ostéoporose et dans celui d'ostéopathie mixte par toxicomanie le dommage causé par la surcharge a abouti à des modifications particulières: Déformation plastique de l'os par remaniement sans fracture ni hypertrophie. Ce sont là des altérations qu'on n'observe pas dans les lésions, par surcharge du tissu osseux normal.

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AUS DEM RÖNTGENINSTITUT (DIREKTOR: PROF. M. LÜDIN) DER UNIVERSITÄT, BASEL, SCHWEIZ.

TOMOGRAMME BEI KNOCHENERKRANKUNGEN[1]

(Osteomyelitis und Fraktur)

von

E. Theilkäs

An Hand zweier Fälle möchten wir kurz auf die Wichtigkeit der Tomographie für die Knochenchirurgie hinweisen. Die Krankengeschichten geben wir mit der freundlichen Erlaubnis von Herrn Prof. SCHÜRCH, Chir. Universitätsklinik, auszugsweise wieder:

Fall 1: Beim ersten Fall handelt es sich um eine 20-jährige Bürolistin, die seit dem 4. Altersjahr an einer chronischen Osteomyelitis des rechten Unterschenkels mit mehreren akuten Exazerbationen leidet. Im Juli 1948 traten wieder Schmerzen und Schwellung am rechten Unterschenkel auf, die ein neues Rezidiv anzeigten.

Beim Eintritt in die chirurgische Klinik am 5. 8. 48 wurde folgender Lokalstatus erhoben: »Der rechte Unterschenkel ist ca. 4 cm kürzer. Entlang der medialen Tibiafläche findet sich eine ca. 20 cm lange und ca. 4 cm breite, unregelmässig höckrige Narbe welche mit der Unterlage verwachsen ist. Im untern Narbenteil ist die Haut stark gerötet, während der proximale Teil reizlos ist. Vom Fussgelenk bis zum Anfang der Narbe ist der Unterschenkel medial geschwollen und stark druckempfindlich.«

Das *Röntgenbild* vom gleichen Tage ergibt einen für chronische Osteomyelitis charakteristischen Befund mit gleichmässiger Verbreiterung des Tibiaschaftes, unregelmässiger, teils sklerosierter Knochenstruktur und mehreren bis 3 auf 4 cm messenden Defekten, die jedoch durchwegs scharfe, teils sklerosierte Ränder aufweisen. Ein frischer Herd lässt sich auf den Aufnahmen nicht mit Sicherheit erkennen (Abb. 1).

Die daraufhin am 18. 8. 48 angefertigten *Tomogramme* zeigen, am deutlichsten in den Schichten um $6^1/_2$ cm, im unteren Tibiaende drei rundliche Aufhellungen (Abb. 2). Ihre Begrenzung ist unscharf, nirgends sklerosiert. Die grösste misst 1.7 auf 1.5 cm, die andern weniger als 1 cm. Sie liegen 1 bis 2 cm vom Sprunggelenk entfernt in einer Tiefe von gut 3 cm von der vorderen Tibiafläche an gerechnet. Weiter oben finden sich die schon auf den Röntgenbildern dargestellten länglicher

[1] Bei der Red. am 14. IV. 1949 eingegangen.

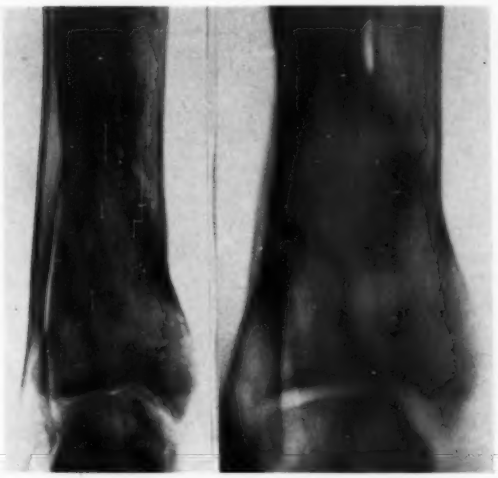

Abb. 1. Abb. 2.

Defekte mit starker Sklerose der Umgebung. Die *Diagnose* lautete: *Frische osteomyelitische Herde im unteren Tibiaende* rechts bei alter Osteomyelitis.

Unsere Annahme wurde durch die Operation vom 21. 8. 48 bestätigt. Nach vorheriger Orientierung nach den Tomogrammen konnte die grösste der Höhlen mit dem Bohrer sofort gefunden werden. Das nekrotische Gewebe wurde mit dem scharfen Löffel entfernt und mit den beiden Nebenhöhlen Verbindung geschafft. Darauf wurde eine dünne Kanüle eingeführt und die Höhle mit Penicillin gefüllt.

Fall 2: Der 2. Fall betrifft eine 53-jährige Frau, die am 26. 7. 48 bei einem Motorradunfall eine Tibiakopffraktur rechts erlitt.

Das *Röntgenbild* ergab eine ins Kniegelenk reichende Y-förmige Fraktur des rechten Tibiakopfes. Die Gelenkfläche erschien sowohl auf der v.-d., wie auf der seitlichen Aufnahme erhalten, so dass der Röntgenologe keine wesentliche Verschiebung der Fragmente annahm (Abb. 3 a, b).

Gestützt auf diesen Befund wurde am 7. 8. 48 eine Gewindebolzung des Tibiakopfes vorgenommen. Dieser Eingriff führte zu einer gewissen Verengerung des verbreiterten Tibiaplateaus, wodurch die Eminentiae intercondyloideae deutlicher hervortraten.

Schon auf dem Röntgenbild (Abb. 3 a) war im Tibiakopf lateral eine eigenartige, ungefähr 3 auf 2.5 cm messende dichtere Knochenpartie mit ziemlich scharfer, bogenförmiger oberer Begrenzung aufgefallen. Da man

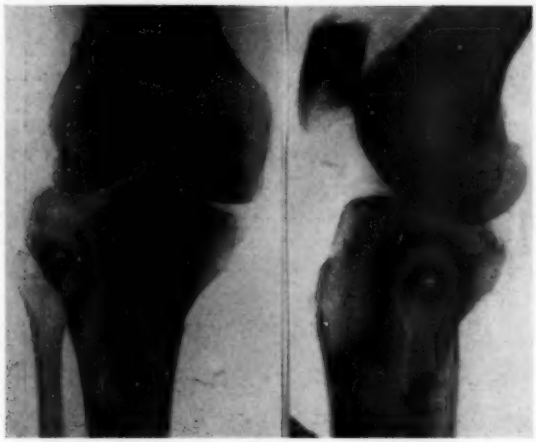

Abb. 3 a. Abb. 3 b.

sich diesen Befund nicht recht erklären konnte, wurde uns die Patientin zur Tomographie zugewiesen.

Die *Tomogramme* vom 17. 8. 48 ergaben: Die Gelenkfläche des rechten Tibiakopfes erscheint hinten (Schicht 11 cm, Abb. 4 a) praktisch intakt. Nach vorne zu, am deutlichsten in den Schichten um 14 cm (Abb. 4 b) ist ein fast 3 cm breites, annähernd viereckiges Knochenfragment mit seiner leicht bogenförmigen Begrenzung keilförmig um 1—2 cm nach unten verlagert. In den vorderen Schichten (15 cm, Abb. 4 c) ist die Gelenkfläche wieder mit normaler Begrenzung zu sehen. Die seitlichen Tomogramme bestätigen diesen Befund und zeigen deutlich, dass der keilförmig nach unten verschobene Knochenteil hinten lateral liegt. Seine Gelenkfläche ist besonders in den Schichten 3 und 4 cm (Abb. 4 d) deutlich zu sehen. Hinten ragt lediglich ein schmaler Knochenpfeiler mit entsprechend kleinem Gelenkteil nach oben, während vorne fast die halbe Gelenkfläche erhalten ist. Die Übersichtlichkeit des Bildes wird durch den Gewindebolzen beeinträchtigt.

Da die Patientin bei guter Beweglichkeit des Kniegelenkes fast beschwerdefrei war, konnte auf eine operative Korrektur verzichtet werden.

Die Tomographie leistet auch bei Knochenerkrankungen grosse Dienste, was nach unseren Erfahrungen weniger bekannt zu sein scheint. So gelingt es oft auf dem gewöhnlichen Röntgenbild nicht sichtbare osteolytische Prozesse entzündlicher oder tumoröser Genese deutlich darzustellen. Besonders bei Osteomyelitis können, wie unser 1. Beispiel zeigt, frische, sonst nicht erkennbare Herde deutlich lokalisiert und der lokalen Penicillinbehandlung zugeführt werden. Auch zum genauen Studium komplizierter Frakturen (Fall 2) hat sich die Tomographie bewährt.

Schicht 11 cm.

Abb. 4 a.

Schicht 14 cm.

Abb. 4 b.

Schicht 15 cm.

Abb. 4 c.

Schicht 3 cm.

Abb. 4 d

ZUSAMMENFASSUNG

Die Tomographie kann bei Knochenerkrankungen grosse Dienste leisten. Auf dem gewöhnlichen Röntgenbild nicht sichtbare osteolytische Prozesse entzündlicher oder tumoröser Genese können oft deutlich dargestellt werden. Auch zum genauen Studium komplizierter Frakturen hat sich die Tomographie bewährt.

SUMMARY

Tomography is a valuable aid in the diagnosis of diseases of the bones. Osteolytic processes due either to inflammatory processes or tumour formation which are not visible in the ordinary radiogram, are often revealed by this method. Tomography also furnishes valuable information in complicated fractures.

RÉSUMÉ

La tomographie peut rendre de grands services dans les affections osseuses. Des processus ostéolytiques d'origine inflammatoire ou néoplasique, invisibles sur la radiographie ordinaire, peuvent être mis distinctement en évidence. La tomographie a aussi fait ses preuves pour l'étude exacte de fractures compliquées.

CLINIQUE CHIRURGICALE (DIR.: PROF. A. JENTZER), INSTITUT DE RADIOLOGIE (DIR.: PROF. L. GILBERT) ET INSTITUT DE MÉDECINE LÉGALE (DIR.: PROF. F. NAVILLE) DE L'UNIVERSITÉ DE GENÈVE, SUISSE.

LA MORPHOLOGIE RADIOLOGIQUE DE L'EMBOLIE GRAISSEUSE DU POUMON[1]

par

Georges Voluter

Parmi les syndromes miliaires du poumon, les mécanismes radio-morphologiques de l'embolie graisseuse tiennent une place à part. Ceci s'explique par leur évolution en plusieurs temps nettement distincts morphologiquement les uns des autres, par le titre radio-absorbant des éléments embolisants, par les particularités stylistiques du cortège des altérations secondaires, évoluant dans le parenchyme pulmonaire et, enfin, par la répercussion de ces mécanismes sur la configuration du cœur.

Il est extrêmement rare de pouvoir suivre *par la radiosériographie*, étape par étape, les différentes phases de l'embolie graisseuse du poumon. Il faut compter, pour réaliser pareille entreprise, sur un hasard extraordinaire. Nous avons eu cette occasion peu commune. Grâce à l'intérêt que porte à nos études le Professeur JENTZER et grâce aux conseils du Professeur NAVILLE qui a le mérite d'avoir éclairci, un des premiers (1913), le problème clinique et physio-pathologique des embolies graisseuses mortelles, nous étions en mesure d'approfondir *l'aspect radio-morphologique* d'une inondation graisseuse aiguë et brutale du poumon, survenue chez un homme de 25 ans, porteur d'une fracture du fémur gauche.

a) Historique

Nous en trouvons un exposé complet fort intéressant dans les publications de C. FROMBERG et de F. NAVILLE parues en 1913.[2,3]

Qu'une émulsion de graisse injectée dans la circulation sanguine d'un

[1] Remis à la rédaction le 19 Avril 1949.

[2] C. FROMBERG: Die Fettembolie des grossen Blutkreislaufes und ihre Ursachen. — Mitteil. aus den Grenzgebieten der Med. und Chirurg.; Bd. 26, Heft 1. Pages 23—38, 1913.

[3] F. NAVILLE: Les embolies graisseuses. L'embolie du cerveau. — Arch. de Méd. et périment. et d'Anat. path.; t. XXV No. 4, juillet 1913. Pages 405—429.

animal puisse être mortelle, a été prouvé par l'expérience de LOWER; elle date de l'année 1669. Cet auteur injecta (d'après son Tractatus de Corda), 19 »Unzen» de lait dans les veines d'un chien qui succomba, peu après, sous les signes de convulsions et de dyspnée violente.

Nous trouvons des imitateurs de cet exploit parmi des chercheurs comme CLARKE, CORTON, KING, DRELINCOURT, GASPARD et BECK. Ce n'est que ce dernier, avide de connaître les troubles mortels de la respiration, qui, en fin de compte, a examiné le poumon de l'animal sacrifié. Intrigué par le problème, MAGENDIE injecta de l'huile dans la circulation sanguine. Il décrit le premier l'obturation huileuse des capillaires pulmonaires.

D'après NAVILLE, les premières constatations de l'embolie graisseuse, en pathologie humaine, ont été faites presque simultanément par ZENKER et WAGNER aux environs de 1862. »Le premier de ces auteurs ne vit dans ses constatations qu'une simple trouvaille d'autopsie à laquelle il n'attribua pas grande importance tandis que WAGNER, en saisissant tout l'intérêt et toute la portée, esquissa tout de suite une théorie générale de l'embolie graisseuse. Il la développa surtout dans des travaux postérieurs à son mémoire initial. Il montra que ces embolies sont parfois la cause directe de la mort; il pensait qu'elles sont surtout en relation avec les suppurations des os et des tissus mous, bien qu'il en eut observé aussi après des fractures non compliquées ou de simples contusions du tissu cellulaire sous-cutané.»

Finalement BUSCH et l'école de v. RECKLINGHAUSEN, entre les années 1866 et 1880, ont établi des bases physiopathologiques plus solides quant aux causes et mécanismes et quant aux effets de l'embolie graisseuse. Ils dénoncèrent les fractures comme mobile par excellence et prouvèrent que la graisse, après des traumatismes osseux, se montre de façon plus constante dans les poumons qu'on ne l'a admis jusqu'à présent; son apparition dans la circulation pulmonaire étant des plus rapides. Ainsi les notions de la précocité et de la généralité, dans tout ce problème ont été acquises très précocement.

Mais fait important, ces auteurs trouvèrent déjà les principes de transport de la graisse, dans les mécanismes embolisants. Quelques heures après la fracture, la graisse, dans les veines les plus proches du lieu du traumatisme, a été introuvable. Ils constatèrent qu'elle envahissait, très vite, les voies veineuses (accessoirement les lymphatiques), en aval, et arrivait ainsi au cœur droit. De là, elle pouvait atteindre la grande circulation et déclencher des hémorragies miliaires dans les organes, reliées à elle.

Parmi l'équipe de v. RECKLINGHAUSEN, FLOURNOY en 1878, dont j'avais le privilège, grâce à l'amabilité de son fils, le Dr HENRI FLOURNOY, de Genève, de consulter la thèse originale et manuscrite d'une belle main,

posa une pierre fondamentale dans l'édifice de la pathogénique de l'embolie graisseuse mortelle. Voici ses conclusions: L'embolie graisseuse n'est pas uniquement l'apanage des fractures; elle peut être due à des contusions et broyements de parties étendues des tissus mous profonds et même des contingents cellulaires sous-cutanés. Elle peut encore démarrer de suppurations osseuses et de préférence d'atteintes ostéomyélitiques. Elle peut, enfin, prendre son départ dans des milieux presque physiologiques, tels la dégénérescence sénile de la moëlle.

Tous les travaux traitant ultérieurement de la question se sont basés sur les constatations expérimentales de FLOURNOY. Ainsi la notion que le simple ébranlement de l'os (RIBBERT, BEITZKE), surtout de petite dimension (vertèbres, côtes, etc.), que le redressement forcé de certaines ankyloses (PAYR, COLLEY) que des coups violents portés (mauvais traitement) contre le corps (BÜRGER, ZIEMKE) pouvaient donner lieu à des embolies graisseuses mortelles, est la suite logique du travail fondamental de l'auteur genevois.

Les années après 1900 ont apporté un nombre croissant de notions nouvelles dans la pathogénie de l'embolie graisseuse. NAVILLE nous en donne le tableau suivant: »Celle-ci (embolie graisseuse) peut enfin être occasionnée par une simple opération aseptique portant sur les tissus gras . . ., ou survenir au cours de l'éclampsie, dans l'intoxication par le chlorate de potasse ou par le phosphore, dans les cas d'emphysème sous-cutané, dans les lipémies diabétiques et après des brûlures étendues. En médecine légale, sa constatation dans les poumons, toutes causes d'erreur étant éliminées, permet probablement d'affirmer qu'une fracture, une contusion, ou une brûlure étendue ont dû précéder la mort, car on ne connaît pas de cas où ces causes, agissant après elle, aient occasionné le transport de graisses jusqu'aux poumons.«

Le critère de l'embolie graisseuse du poumon est sa complication mortelle: l'embolie graisseuse consécutive du cerveau. Cependant celle-ci est rare. Du temps où NAVILLE a écrit sa magistrale étude, c'est-à-dire en 1913, il n'a pu relever que 17 cas dans la littérature médicale. Quant à l'iconographie radiomorphologique des différentes étapes embolisantes, dans le territoire cardio-pulmonaire, nous n'avons trouvé aucune indication dans la bibliothèque roentgénienne des deux mondes.

L'exposé qui va suivre aura donc d'autant plus d'intérêt qu'il relèvera des faits physio-pathologiques, intra vitam, dont les péripéties ni les traces ne sont décelables, intégralement, sur les pièces nécropsiques. Cependant pour ces raisons même, nos conclusions ne sont pas exemptes de toute critique objective, parce que la preuve anatomo-pathologique leur fait défaut. Mais, en nous basant sur les données expérimentales acquises, elles auront une valeur relative.

b) Mécanismes physio-pathologiques

Dans les expériences faites par WAGNER, FLOURNOY et RIBBERT, l'embole graisseux, amassé dans le cœur droit, doit y rester accroché un certain temps avant que, brassé et dilué, il arrive dans les ramifications, de différents calibres, de l'artère pulmonaire. Selon la force du »piston» cardiaque, il arrive, plus ou moins vite, d'abord dans le réseau »de second ordre» et enfin dans le système capillaire. Ainsi le transport graisseux, selon sa masse et selon les forces qui le poussent en avant, peut se faire vite ou lentement. Encore faut-il tenir compte du fait que dans les fractures, l'embolie graisseuse n'est pas toujours un accident de la première heure; elle peut être tardive et être provoquée sous les secousses du membre traumatisé, p. e. pendant un déplacement ou pendant un long transport (SKIRVING).

Dans le cas dont nous allons parler, tout à l'heure, l'embolie est justement survenue quelques jours après l'accident probablement lors d'un léger mouvement de la jambe dans le lit du malade.

Physio-pathologiquement, nous sommes en présence de l'invasion successive de deux territoires circulatoires lorsque la mort s'ensuit par embolie graisseuse du cerveau. Il s'agit d'abord d'une embolie pulmonaire proprement dite et, en second lieu, d'une embolie paradoxale de la grande circulation.

NAVILLE a le mérite, en se basant sur une observation de ZAHN, d'avoir démontré que pareils mécanismes ne sont possibles que si *le trou de Botal est ouvert*. »On conçoit que la démonstration directe du passage d'un sang, chargé de graisses, à travers ce même orifice ne pourra malheureusement jamais être fournie par une constatation semblable», tout en citant le fait que ZAHN, en trouvant un thrombus à cheval sur les bords du Botal apporta la preuve que des embolies paradoxales des masses solides se font grâce à la persistance d'un passage ouvert entre le cœur droit et gauche. Il dit plus loin: »Notre manière de voir ne peut pas non plus recevoir sa confirmation de l'étude des autopsies d'embolies graisseuses de la grande circulation publiée jusqu'à ce jour, car, dans aucune d'elles (sauf les deux cas de BÜRGER) il n'est pas fait mention du trou de Botal. Nous pensons cependant que les symptômes d'embolie cérébrales, observées à très court intervalle après les fractures, s'expliquent mieux par notre hypothèse que par celle d'un passage de la graisse à travers les capillaires des poumons.» Il cite alors les observations de GRÖNDAHL, de BEIZKE, de BENESTAD et de COLLEY, *où les signes d'une embolie graisseuse du cerveau se sont déclarés dans les premiers instants qui suivirent le traumatisme osseux*. Et voici ses conclusions: »Des faits semblables, mis en regard des constatations anatomiques déjà anciennes qui prouvent que le cœur a parfois besoin de plusieurs heures pour amener la graisse jusque dans les

artères pulmonaires de petit calibre, nous semblent difficilement explicables par l'hypothèse d'un passage *aussi rapide d'une si grande quantité de graisse à travers les capillaires du poumon.*»

Ouvrons ici une parenthèse: Les données récentes (FELIX MULLER, VON HAYEK, MILLER, POLICARD) de l'étude physio-anatomique et physiopathologique du système capillaire des poumons confirment — elles les vues de l'auteur?

Or, les anastomoses entre les artères pulmonaires et le système veineux des parois bronchiques passent à travers le »pont» d'artérioles qui sont histologiquement des segments d'arrêts.[1] Ces derniers sont constitués par des tuyaux minuscules qui débouchent des collatérales d'un diamètre de 0.25 mm et qui viennent d'une artère bronchique 4 fois plus grande. Elles se dirigent très souvent en sens inverse, vers le filet veineux pariétal d'une bronche exempte de cartilage et d'éléments glandulaires. Ainsi nous sommes en présence de l'anastomose artério-veineuse, fait important qui explique le passage direct du sang dans la veine pulmonaire à travers les filets pariéto-bronchiques. *C'est la première dérivation: la parenchymateuse.* L'autre, la seconde, se passe dans le *feuillet pleural*, et là elle se fait dans des zones électives. Le mécanisme est le suivant: artère pulmonaire — artère bronchique — veines souspleurales — veines interlobulaires superficielles. Ici le cour-circuit est moins long.

La quantité de sang qui est ainsi court-circuitée dépend tout simplement de la *lumière* des anastomoses. Celle-ci, rappelons-le, est encore soumise à un bon nombre de facteurs vaso-moteurs. La masse sanguine est parfois si importante dans le dédale pariétal d'une bronche, qu'elle donne lieu à une compression du canal bronchique et par cela à des troubles de la ventilation alvéolaire dépendante. Comme le dit POLICARD, il faut envisager ainsi une régulation synchrone de l'irrigation sanguine et de l'aération de certains territoires pulmonaires.

Dans le système capillaire des territoires artériels pulmonaires et bronchiques les anastomoses se font au niveau des bronchioles respiratoires dont les capillaires sont issus de l'artère pulmonaire.

Ainsi un embole ou un produit irritatif mécanique, toxique ou bactériel peut être transporté de la petite circulation dans la grande circulation sans emprunter le chemin à travers les cavités cardiaques. (Trou de Botal ouvert.) Mais il peut être confiné sur un seul territoire circulatoire du moment que les »ponts de dérivation» sont barrés par une mécanisme

[1] L'on trouve encore des »artères d'arrêt» dans la thyroïde, le rein, la prostate et les organes génitaux. Elles se caractérisent par des dispositifs musculaires longitudinaux. Les cellules constitutives de ces éléments musculaires sont très souvent issus d'une transformation épithéloïde. Les fibrilles ne se distinguent plus. La lumière du vaisseau est rétrécie par tous ces éléments. L'intima, et avec elle l'élastica interna s'insinue entre les faisceaux longitudinaux, d'où un aspect général plissé.

quelconque dans les artères d'arrêt. Ces dernières peuvent s'oblitérer par contracture, passagère et chronique; elles peuvent encore être complètement bouchées par des thromboses, des processus intrin- et extrinsèques.

Dans la mort par embolie pulmonaire le volume de l'élément embolisant peut être extrêmement réduit et la cause de la mort, d'après les expérimentations de BINET et BURSTEIN, est due essentiellement à l'obstacle du passage du sang au niveau du poumon au cours des embolies mécaniquement non oblitérantes. Voici ce qui se passe:

Les parties embolisantes éveillent la sensibilité endovasculaire du poumon et déclenchent un réflexe vaso-constricteur local. L'oblitération artérielle, peu importante du point de vue mécanique, s'accompagne ainsi d'une vaso-constriction réflexe intense. Le barrage pulmonaire réalisé de la sorte est la cause d'un trouble de distribution du sang entre le système artériel et le système veineux, d'où hypertension veineuse, hypertension dans l'artère pulmonaire, arrivée insuffisante du sang dans l'oreillette gauche et par conséquent diminution du débit systolique du ventricule gauche.

Les veines bronchiques ont un territoire moins étendu que les artères. A l'état normal, d'après les confirmations de BERRY et de BURGH DALY, les veines bronchiques évacuent un tiers et les veines pulmonaires, deux tiers du sang circulant dans les artères bronchiques.

Celles-ci assument non seulement la nutrition de la paroi de la bronche, mais encore celle des tissus englobés dans l'interstice, celle des parois des artères, des veines et des éléments et vaisseaux lymphatiques. C'est d'elles que dépend la vie intérieure de l'architecture pulmonaire. L'artère bronchique commande en premier lieu à la fonction intrinsèque du poumon.

Mais dans les parois des bronches nous trouvons encore des »lits veineux» dont le rôle n'est cependant pas négligeable. Ces lits ou plexus veineux naissent du réseau capillaire de la muqueuse bronchique par le truchement d'un système capillo-veineux. Nous constatons un premier plexus dans l'épithélium et la musculature, nommé plexus interne ou encore intramuqueux. Le second plexus, appelé externe ou sous-muqueux, se place en-dessous de la musculature et s'appuie contre la tunique fibro-cartilagineuse. Il est relié au premier par de très courtes branches à la manière de racines veineuses. Son développement est spécialement remarquable dans toutes les petites bronches.

Ce plexus à double étage émet des veines qui se caractérisent par deux dispositions spéciales. POLICARD et GALY les décrivent ainsi: Au niveau des grosses bronches seulement (celles correspondant aux deux ou trois premières divisions), ces veines constituent les voies de retour propres à cette partie des bronches, les veines bronchiques proprement dites, aboutissant soit à l'azygos, soit dans une veine intercostale, soit directe-

nent dans la veine cave supérieure. Ces veines peuvent recevoir aussi ces rameaux provenant de la plèvre au voisinage du hile! Mais à partir des bronches moyennes, dans tout le reste de l'arbre bronchique, le plexus profond donne naissance à des rameaux qui sont une source de veines pulmonaires. Ces rameaux sont les veines bronchopulmonaires de LE D'ORT.

Ainsi, le sang venu par l'artère bronchique se jette dans le système des veines pulmonaires; celles-ci constituent les affluents du sang ayant irrigué les bronches.

Mais dans les bronches à petit calibre (1 à 2 mm) s'ajoute à ces lits veineux un autre réseau important celui des capillaires lymphatiques. Les deux formations constituent le coussinet veino-lymphatique qui dans les bronches, exemptes de cartilage et de glandes, joue, d'après VON HAYEK, un double rôle fonctionnel de premier ordre.

Voyez la complexité vasculaire de ces coussinets. Ses veines puisent leur sang dans deux réseaux à la fois: celui des artérioles bronchiques, du réseau capillaire et du plexus veineux superficiel d'une part et celui des vaisseaux anastomotiques à type »d'artères d'arrêt», unissant ainsi ces vaisseaux avec les branches de l'artère pulmonaire d'autre part.

Le coussinet lymphato-veineux protège le »fêtu» bronchiolaire contre l'influence mécanique du milieu ambiant et aussi contre son dérangement fonctionnel en cas d'un processus morbide aigu, chronique ou sclérosant dans les alentours. Ce même coussinet est très souvent en cause lors d'un rétrécissement de la lumière bronchique dès que le sang afflue en trop grande quantité dans l'espace rigide entre musculeuse et tunique cartilagineuse et lorsque la musculature, par contraction, chasse ce débit sanguin important après ouverture des écluses battant les artères d'arrêt dans les lits veineux.

Alors nous pouvons assister à une gêne d'une part, du passage de l'air dans les sacs alvéolaires et d'autre part, à des troubles de la fourniture sanguine (débit amoindri au territoire pulmonaire correspondant).

Dans l'asthme bronchique, VON HAYEK pense que les plissements exagérés de la muqueuse et leur gonflement issus du regorgement en sang du coussinet, augmentés encore par la contraction de la musculature sont à leur paroxysme à la suite de l'intervention parallèle de l'œdème de la muqueuse et du spasme musculaire.

Voici, vu à la lumière des dernières et toutes récentes explorations, le dédale capillaire du poumon. Serait-il possible qu'une masse embolisante comme l'est un contingent graisseux, charrié dans la petite circulation, puisse franchir ce labyrinthe pour arriver en fin de compte, en assez grand nombre, pour déclencher une embolie mortelle du cerveau? Ce n'est pas possible. Admettons, que, dans des circonstances extraordinaires, quelques gouttelettes puissent traverser les différents segments, elles ne pourraient, toutefois, pas former la quantité nécessaire à fomenter des

troubles, dans la grande circulation, tels que nous les constatons macro et microscopiquement.

D'autre part, il ne faut pas négliger les capacités lipodiérétiques du poumon; car nous savons que les cellules alvéolaires sont, par dessus le marché, dotées d'un principe métabolique qui coexiste avec le principe phagocytaire. Leur ferment lipolytique entre d'ailleurs en action dans des conditions absolument physiologiques.

Si le sang parcourt, en pleine phase de digestion, le poumon, il y perd jusqu'a 30 % de ses lipides. Ces derniers, peuvent, dans certains cas, s'accumuler par insuffisance de la digestion pulmonaire. Ils peuvent aussi envahir le poumon en trop grandes quantités, comme cela arrive dans l'éclampsie. De véritables embolies graisseuses sont dues encore au tétanos.

Il est certain que le poumon dans ces inondations pathologiques, fasse un effort pour digérer les graisses, mais très tôt, vu les altérations collatérales, cet effort est paralysé.

Somme toute, NAVILLE *a parfaitement raison en supposant: pas d'embolie graisseuse importante, mortelle, sans perméabilité du trou de Botal.*

Dans sa thèse sur les inclusions cholestéroliques dans les pneumonies interstitielles chroniques, FABRE traite, de façon très précise, du rôle de la lipodiérèse pulmonaire. Voici ce qu'il dit:

»C'est en 1922 que ROGER et BINET ont créé le terme de lipodiérèse pulmonaire pour désigner la destruction des graisses par le poumon. En ponctionnant simultanément l'artère fémorale et le cœur droit, ils constatent que le sang des artères est sensiblement moins riche en lipides que celui des veines qui n'a pas encore franchi le réseau capillaire du poumon. Dans une autre expérience, ROGER et BINET comparent la teneur en graisses d'organes dont une partie est fixée par chauffage et une autre conservée à 38° pendant 18 heures dans une solution de fluorure de sodium pour éviter toute putréfaction. Pour 100 gr. de graisse ils constatent, dans les échantillons non fixés, une perte par lipodiérèse de 40 gr. dans le foie et 39 dans le poumon, tandis que le déficit est notablement moins important dans les autres organes (12 gr. dans les muscles par exemple); la destruction des graisses est de 39 gr. dans le sang artériel. En revanche, la lipoidérèse est nulle dans le sang veineux; elle augmente si on fait passer un courant d'oxygène, sans toutefois atteindre celle du sang artériel, ce qui indique que l'oxygène joue un rôle dans la lipodiérèse mais qu'en outre les poumons confèrent une propriété spéciale au sang qui les traverse, peut-être par formation d'un enzyme lipolytique.

Mais avant de détruire les graisses, les poumons les fixent; c'est ce qu'ont démontré EUSQUET et VISCHNIAC en enlevant un poumon à un chien et en lui injectant de l'huile dans la veine saphène. Un quart d'heure après, ils enlèvent le poumon qui reste: il contient 10 fois plus de graisse que le témoin. Le pouvoir de fixation serait 9 fois plus fort que celui des reins, 45 fois plus que celui du foie. Même si l'huile est injectée dans la veine porte, *la fixation du poumon serait plus forte que celle du foie*, premier organe traversé.

Les expériences les plus variées ont conduit aux mêmes conclusions: le poumon est un organe de fixation puis de destruction des graisses. Grâce aux réactions des aldéhydes de FEULGEN et VERNE, on peut suivre histologiquement les phases de la lipodiérèse pulmonaire. Pour plus de détails, nous renvoyons aux travaux de FREYHER, QUENEL et SEEMAN.

A vrai dire, la lipodiérèse pulmonaire est un phénomène complexe. Au niveau des poumons, les lipides peuvent être:

1) Entassés dans les capillaires.

2) Captés par les cellules épithéliales alvéolaires, qui desquamment et s'éliminent par les voies respiratoires, ou par les cellules du système réticulo-endothélial (BINET, AUBEL et MARQUIS).

3) Mis en réserve dans les pelotons adipeux péribronchiques.

4) Lipolyse par enzyme dont l'action serait favorisée par la présence d'oxygène.»

Il est fort probable que l'inondation graisseuse lors d'un traumatisme même léger (contusion, entorse, chute, etc.) soit pour ainsi dire un phénomène para-physiologique. Il dépend de la constitution pulmonaire (dans le sens de POLICARD) si de pareils accidents ne dégénèrent pas en véritables embolies graisseuses. Encore celles-ci, même dans leurs formes pathologiques, sont-elles susceptibles de passer inaperçues, au moment où la fonction lipodiérétique du poumon se trouve dans un équilibre parfait. Mais celle-ci peut dépendre d'éventualités fort complexes. Nous ne voulons pas insister, dans le cadre de ce travail, sur ce sujet. *Cependant rappelons-nous qu'un individu diabétique, d'autres encore, chez lesquels le métabolisme basal est en désordre (rôle de l'acidose locale, etc.) sont sujets à des prédispositions qui, sans doute, favorisent l'établissement de l'embolie graisseuse du poumon.*

c) Données anatomo-pathologiques

Lorsque nous étudions les effets de l'embolie graisseuse du poumon, *lors de l'autopsie*, nous décelons les états suivants (notons que les aspects post mortem ne peuvent pas, in toto, nous renseigner sur les altérations successives qui ont eu lieu lors du démarrage de l'embole):

D'après NAVILLE les poumons sont, dans leur ensemble, hyperémiés. Il y a de l'œdème et un emphysème qui varie dans de larges limites d'un cas à l'autre. »Parfois on y voit de petites hémorragies de la dimension de têtes d'épingles, et beaucoup plus rarement des hémorragies étendues, dues à l'oblitération ou à la rupture d'un vaisseau. *Le réseau capillaire est plus ou moins envahi par la graisse.* Il l'est toujours également dans toutes les parties du poumon. Il l'est parfois avec une telle abondance que la graisse arrive à occuper, sur les préparations fraîches, le tiers du champ microscopique.» Ici l'on constate généralement des capillaires dilatés à l'extrême. Les vaisseaux sont bourrés de graisse à laquelle est entremêlé un plus ou moins fort contingent en globules rouges. Les cavités alvéolaires sont remplies de polynucléaires, de fibrine, de cellules épithéliales desquammées. Il y a, ça et là, de véritables hémorragies alvéolaires qui varient avec des complexes de pneumonie fibrineuse. Fait important, la graisse est introuvable dans l'épithélium, dans les lumières

alvéolaires et dans le tissu conjonctif. Les polynucléaires, non plus, ne renferment pas de traces de graisse. Mais à ce tableau il y a des exceptions. Certains auteurs et parmi eux RIBBERT ont constaté qu'il y a des variations quantitatives selon l'importance et la fréquence des emboles graisseux. Il y a des mécanismes où ces derniers peuvent se greffer les uns sur les autres. Alors on peut voir une véritable inondation, à la manière de couches géologiques, selon l'ancienneté et la jeunesse des greffons, de tous les contingents fixes et mobiles du territoire inondé. On a décrit des tableaux où plus de la moitié du réseau artériel a été submergée; dans des cas pareils, l'extravasation graisseuse peut être énorme.

Quant au cœur, NAVILLE fait la description suivante:

A l'autopsie »le cœur, dont le ventricule droit est toujours dilaté, présente de nombreuses ecchymoses à sa surface externe comme à sa surface interne. Sous l'endocarde et à la coupe du myocarde, on voit de nombreuses stries jaunâtres qui correspondent à des régions où les fibres musculaires sont en dégénérescence graisseuse. Au centre de ces stries, on aperçoit régulièrement un capillaire obstrué par de la graisse, et parfois entouré d'une petite zone hémorragique.» *Cette dégénérescence graisseuse de la fibre cardiaque est très fréquente et très précise.* GRÖNDAHL *l'a trouvée déjà répandue chez une jeune fille morte 7 heures après une fracture.*

La graisse pourrait également obstruer des artères cardiaques de moyen calibre, et occasionner par là des lésions nécrotiques mortelles. COLLEY a ainsi rapporté l'observation d'un jeune homme de 14 ans, qui, étant en pleine convalescence d'une fracture infectée du tibia datant de 8 semaines, fut subitement pris de convulsions, *sans aucun prodrome.* Il râla un instant et mourut très rapidement. A l'autopsie, on trouva un foyer de myocardite ancienne gros comme une pièce d'un franc, situé sur la paroi interventriculaire et très probablement dû à une embolie graisseuse datant de la fracture.

Le cas que nous rapportons ici est celui d'un jeune homme, *très maigre*, qui s'est fracturé, dans une chute, le fémur gauche. La radiographie avait relevé de nombreux fragments et de grossiers déplacement des os. L'accident avait, en outre, provoqué des contusions superficielles à divers endroits du corps, du nez, au menton et à la face du côté droit.

A l'autopsie, on a constaté une rupture de la plèvre entourant le médiastin postérieur à gauche avec un fuseau de suffusions hémorragiques entourant la moitié inférieure de l'aorte et de l'œsophage. Tout cela nous a échappé lors de l'entrée du blessé à la Clinique du Professeur Jentzer, parce que l'état du malade ne faisait pas penser à un traumatisme endothoracique. D'ailleurs, vu ses douleurs et vu son état général, on a fait

le strict minimum du point de vue radiologique, quitte, une fois le malade apaisé, de procéder à des examens complémentaires.

Dès le premier jour, on a mis le membre fracturé en extension. Tout alla bien, lorsque le sixième jour, sans que nous connaissions les raisons exactes, le malade tombe d'un bien-être relatif, subitement au cours de l'après-midi, dans un sommeil comateux. Le chirurgien posa immédiatement le diagnostic d'embolie graisseuse; mais pour éviter de passer à côté d'une fracture crânienne, avec hémorragie tardive éventuelle, il fit encore procéder à une radiographie de la tête qui d'ailleurs ne révéla aucune lésion osseuse.

Cependant nous voulions encore voir s'il y avait des fractures costales et si l'embolie graisseuse produisait des images radiomorphologiques spéciales dans le poumon. C'est ainsi que nous avons pu obtenir par sériographie les documents dont nous vous donnons, dans leur succession, les analyses suivantes:

d) Données radio-morphologiques

Nous sommes en présence d'une embolie graisseuse du cerveau qui s'est établie, à juger d'après ses signes cliniques et d'après la respiration du Cheyne-Stokes survenues brusquement, il y a 26 minutes environ. Quelles sont *les manifestations pulmonaires radiooptiques* concomitantes de pareil état?

Les deux plages pulmonaires présentent, à ce moment, dans les régions parahilaires immédiates, de façon presque symétrique, des agglomérations en forme de boules de neige, de la grosseur allant d'une cerise à une balle de golf. Du côté droit, l'on constate encore deux grands agglomérats, superposés, dans la portion sous-pariétale supéro-moyenne. Ça et là, dans la projection périphérique externe (par rapport aux hiles), l'on voit de grosses bulles emphysémateuses entourées d'un halo exsudatif. Tout le parenchyme environnant est d'ailleurs emphysémateux (emphysème vicariant et irritatif).

Le cœur n'est pas agrandi. Le ventricule gauche est un peu bombé dans la portion D_1. Mais l'oreillette droite ne fait pas saillie. Dans les conditions devant lesquelles nous nous trouvions, il nous a été impossible de contrôler l'ectasie du *segment d'expulsion* du ventricule droit.[1] En tout cas les contractions cardiaques nous frappèrent par leur grande amplitude (effort de vaincre le barrage). *Le tonus du cœur n'était nullement affecté.*

[1] D'après les travaux de l'équipe de l'Institut cardiologique de Mexico, le ventricule droit est, fonctionnellement, divisé en une *portion d'arrivée* et en une *portion d'expulsion*. Ces deux portions forment dans leur ensemble un U dont la branche droite correspond au »réceptacle», la branche gauche à »l'égestoire». Dans le barrage de la petite circulation (phase II et III du cœur pulmonaire) l'on voit, sur le profil et dans le diamètre I et II,se détacher le secteur égestoire en forme de voussure.

Si l'on épluche à la loupe les foyers pulmonaires on peut relever des détails intéressants: Les agglomérats grossiers sont constitués par un amas de micro-foyers infra-acineux dont la plus grande partie est balayée par l'emphysème lorsqu'ils se trouvent disséminés dans ces territoires où il n'y a pas eu d'agglomération. Les »boules» agglomérées n'ont pas une surface lisse, mais sont bordées par des halos infra-acineux en »neige fondante».

En examinant la disposition générale de ces petits et grands foyers l'on décèle un *arrangement radiaire*. Ceci plaide pour le »placement» de ces foyers dans la petite circulation; nous sommes donc en présence d'un style miliaire. Mais si l'on pousse cette investigation plus loin, on découvre une deuxième constellation stylistique, qui ressort nettement de l'image du plan arrière du poumon droit (Fig. 1). A côté des foyers infra-acineux sporadiques et agglomérés, l'on distingue des formations plus radio-absorbantes, de caractère stellaire. Celles-ci sont de la grandeur d'un acinus. Elles correspondent à ces foyers »étoilés» dont nous venons de parler, *qui ont persévéré dans les phases ultérieures de l'imagerie sérioradiographique*, alors que tout le carrousel des contingents de la phase agglomérée avait disparu. Nous avons conclu, en les interprétant sur le plan radio-physiologique, qu'ils étaient des ressortissants morphologiques de grande circulation. Ainsi nous sommes en présence de deux plans radio-morphologiques; sur le premier sont inscrits les éléments logés dans la petite circulation; sur le second ceux de la grande circulation.

Il est frappant de voir dans cette première phase radiomorphologique, saisie dans la 26e minute après le coma, des agglomérats et des foyers solitaires d'un *titre radio-absorbant relativement élevé*. Nous trouvons ici une certaine analogie avec la structure radiologique du NIEMANN-PICK pulmonaire, où le substratum anatomique est formé par des dépôts de lipoides et phosphatides dans les cellules alvéolaires, extrêmement gonflées. Celles-ci forment, au fur et à mesure que les processus de bourrage graisseux augmentent, de véritables complexes acineux. C'est pour cela que leur effet radio-optique se rapproche de la constellation acino-exsudative. L'ensemble et le style de cette altération se distinguent encore par deux caractères presque constants: d'abord par leur massivité radio-absorbante dans les régions hilaires et parahilaires, secondo par l'impression d'un »dessin tressé» à direction plus horizontale que radiaire (Fig. 2). Dans la période d'état du NIEMANN-PICK, le détail du foyer acineux change. Nous voyons apparaître une constellation folliculaire en petites haltères ou en étoiles. Ce dessin folliculaire, vu à la loupe, est crayeux et homogène. Il rappelle exactement les foyers étoilés que nous venons de signaler comme second plan dans notre tableau, et que nous avons classés comme éléments graisso-embolisants de la grande circulation.

Il est probable que les gros agglomérats et leurs satellites de peti

Fig. 1. Détails dans la portion parahilaire et supéro-moyenne sous-pariétale droite.

Dans la phase agglomérée, première étape de l'inondation graisseuse et médullaire, l'on distingue deux plans stylistiques qui relèvent d'éléments placés dans le district de la petite et de la grande circulation. Le plan de la petite circulation est marqué, d'une part, par les gros agglomérats, d'autre part, par les foyers de constellation infra-acineuse. Le second plan, celui de la grande circulation, présente des foyers à constellation étoilée; celle-ci est l'élément persévérant du tableau radiomorphologique fugace.

Le cliché a été pris 26 minutes après l'apparition du coma.

calibre des premiers plans fussent déjà constitués avant que l'accident cérébral survienne; cela veut dire avant l'atteinte de la grande circulation. En d'autres mots: une embolie graisseuse du poumon, d'une envergure notable dans la petite circulation, pourrait-elle passer inaperçue? Le fonctionnement des mécanismes respiratoires ne serait-il pas lésé; n'y aurait-il pas de signe clinique, ni objectif ni subjectif?

Avant de répondre à la dernière question, discutons le problème de la

Fig. 2. Syndrome pulmonaire de la Maladie de Niemann-Pick.

L'image de fond est une constellation exsudative (acineuse), dont la disposition radiaire est, avant tout, horizontale. Voyez le »style tressé« de l'ensemble et le hile en »jet de boue«.

Titre radio-absorbant élevé!

radio-absorption intense des foyers du premier plan, donc ceux placés dans la petite circulation.

Dans toutes les images qui résultent, dans le poumon, des troubles issus d'un bourrage graisseux pathologique, nous retrouvons, selon le déséquilibre de base, à côté des lipoides, des phosphatides et des cristaux de cholestérol. Mais ces éléments ne sont pas pourvus d'un titre radio-absorbant spécialement élevé. Alors faut-il admettre que d'autres contingents, plus radio-absorbants, entrent en jeu? Cependant ces contingents, tout comme les éléments graisseux et leurs satellites, sont encore très fugaces, comme nous le verrons dans la suite. Tout ce tableau de la phase radio-morphologique de la *26e minute* aura changé, de façon étonnante, quant au style fondamental et quant au titre de radio-absorption, dans les vingt-quatre heures. D'après notre avis, il ne pourra s'agir, dans ce phénomène de haute radio-absorption fugace, que de sels de la gamme inorganique et peut-être aussi d'halogènes, appelés sur les lieux par l'irritation alvéolaire.

Car dans tout événement irritatif du poumon, nous devons compter avec l'effet radio-optique des sels minéraux. Certes, dans les affections aiguës nous ne reconnaissons pas si explicitement les différents éléments de la concentration saline. On s'est avant tout préoccupé du problème dans les altérations chroniques, comme la tuberculose, et dans les pneumopathies les plus diverses, de préférence dans la silicose. Cependant, par analogie avec les recherches de MELTZER et de ses collaborateurs, nous pouvons faire les mêmes conclusions quant aux phases précoces des processus pulmonaires; car les mêmes lois doivent jouer pour tous les tissus.

Les troubles qui se manifestent dans le poumon, parenchyme respiratoire, interstice, contingents lymphoïdes, réseaux vasculaires, membranes séreuses, ont une répercussion précoce sur l'équilibre des sels; d'autant plus qu'ils sont responsables de l'harmonie des relations cellulaires et des échanges métaboliques locaux.

On peut distinguer quatre groupes principaux de sels. Ceux du calcium, du magnésium, du fer et des phosphates. Les quatre sont radio-absorbants.

Les différents sels semblent avoir des affinités spéciales pour certains contingents cellulaires. Ils sont, pour ainsi dire, qualitativement et quantitativement fixes dans les tissus en état physiologique normal. Les processus inflammatoires les disloquent, en rompant l'équilibre de leur répartitition cellulaire. Ils les soumettent, en outre, à des fluctuations, plus ou moins prononcées, selon l'importance et la véhémence de l'agent altératif.

Les troubles salins sont repérés et classés à l'aide des méthodes de la micro-incinération histologique. Celle-ci nous révèle les aspects pathologiques des tissus par la désintégration de la structure inorganique, comme le ferait la technique habituelle des colorations d'après les indices cytologiques.

Nos méthodes radiologiques courantes seraient-elles capables d'enregistrer également pareils événements? Certainement! Il faut présumer deux phénomènes radio-optiques, qui vont de pair dans toute altération tissulaire: l'un provenant des fonctions troublées de la structure organique et l'autre découlant du déséquilibre de la structure inorganique.

Dans l'inflammation, la réaction inorganique précède généralement la réaction organique. Réaction organique et réaction inorganique peuvent donc se faire séparément. Cependant, elles peuvent être associées, mais être assujetties en même temps, à des rythmes différents. Nous devons donc assister à des phénomènes de cumul et d'interpénétration. Ces mécanismes doivent avoir des effets radiooptiques différents. Des nuances apparaîtront selon le moment donné d'un processus en cours, selon la nature et selon la réponse organique et inorganique du terrain. Ces effets pourraient se traduire non seulement par des différences d'intensité de radio-absorption, mais également par les différences architecturales dans le détail et dans l'ensemble des éléments radio-morphologiques.

Ainsi ce que nous interprétons comme emphysème circonscrit ou généralisé n'est peut-être souvent qu'un déplacement d'un ou de plusieurs groupements salins, et ce que nous diagnostiquons comme atélectasie ou

atélecto-exsudation ne serait dû qu'à un mécanisme de concentration saline. Cela est surtout vraisemblable dans les cas où les effets négatifs ou positifs de radio-absorption manquent dans une structure architecturale provenant de contingents systématisés, soit par le réseau vasculaire ou lymphatique, soit par le parenchyme respiratoire proprement dit.

D'autre part, certaines images »systématisées», à l'état physiologique normal, qu'elles soient issues de l'interstice ou de la masse bronchiolo-alvéolaire, pourraient être provoquées uniquement par la structure inorganique.

En fin de compte, nous pouvons dire que l'image radiologique du poumon normal dépend de l'harmonie et de l'équilibre régnant dans les sphères inorganiques et organiques. L'image pathologique est due aux reflets radio-optiques des perturbations, existant dans l'une ou l'autre ou dans les deux sphères simultanément. Elle est influencée dans son expression par le cumul et l'interférence des éléments radio-absorbants issus des deux milieux.

Le poumon favorise l'enregistrement de ces phénomènes grâce à sa pneumatisation et à son dessin finement systématisé, et le film est capable de signaler et de relever les contrastes les plus insignifiants.

En dehors de »l'imagerie statique» de certaines ombres pathologiques, leur fugacité exceptionnelle doit nous inciter à les mettre sur le compte de la mobilité extrême de la substance inorganique. Il y a des apparitions explosives et des disparitions foudroyantes de nappes homogènes qu'on a longtemps interprétés comme étant d'origine atélectasique et qui ne sont vraisemblablement dues qu'à des mouvements salins. En fin de compte on pourrait encore soupçonner les mêmes éléments salins, avec leur hiérarchie si ponctuelle dans l'apparition et la disparition successives au lieu d'irritation, dans les »fluctuations nuancées», de certains blocs atélecto-exsudatifs. Même dans la constellation scléreuse et productive, l'imbibition prodromale ou ultérieure en sels doit être un facteur radio-absorbant plein de nuances intrinsèques et extrinsèques. Dans la fibrose, l'incrustation saline n'est pas à discuter et dans les mécanismes régressifs ganglionnaires elle est la règle. Et là encore et dans leurs manifestations dans les tissus cirrhotiques, hyalineux et cicatriciels les fluctuations salines peuvent se perpétuer.

Relevons, avant de terminer, le fait important de la résorption calcaire, parfois très rapide, dans les foyers crétacés de souche lobulaire, dans les éléments lymphoïdes et l'interstitium, dans les ganglions des hiles et dans les masses lymphomédiastinales. Ainsi l'absence de traces de chaux dans le poumon n'est de longtemps pas une preuve qu'un accident de primo-infection ou un autre processus altératif n'ait eu lieu. Le poumon est un organe qui brasse continuellement ses éléments; nous voyons en peu de temps se constituer d'immenses couennes pariétales ou scissurales, des scléroses hilaires et interstitielles massives et nous voyons disparaître, avec le temps, tous ces complexes de réparation cicatricielle.

D'un autre côté, la présence de nombreux foyers calcaires disséminés en style miliaire, ou localisés en groupe bipolaire ou solitaire, ne permet pas d'affirmer que ces »vestiges» aient à leur base d'anciens processus tuberculeux. Les auteurs américains ont encore insisté, ces derniers temps, avec vigueur sur le fait que pareilles formations peuvent être la manifestation de processus banaux fort complexes (larves d'ascarides, éliminées par calcification, dans les processus d'arrêt, etc.).

L'origine des calcifications miliaires symétriques et homogènes dans les deux plages pulmonaires ont donné lieu à de nombreuses discussions dans la littérature américaine. Les uns les considèrent comme les résidus de tubercules miliaires, d'autres les interprètent comme cicatrices calcifiées de minimes foyers bronchopneumoniques. SUTTERLAND pense à une anomalie du métabolisme calcique. On les a décrites parmi les mineurs, on les a soupçonnées d'avoir à leur origine un processus mycotique. Des larves d'ascarides arrêtées dans le piège pulmonaire et calcifiées ensuite ont été également envisagées.

D'après ce que nous venons d'exposer, il est probable que l'embolie graisseuse à la suite du dérangement du métabolisme local et aussi général, à la suite de l'irritation mécanique, à la suite des troubles circulatoires encore, puisse déclencher d'emblée la mobilisation de la masse inorganique. Celle-ci doit donc être, pour une partie du moins, à la base du phénomène radio-absorbant intense des premiers aspects radiologiques des phénomènes pulmonaires. C'est une hypothèse qui est exclusivement basée sur le caractère radio-kinétique.

Envisageons dès maintenant l'autre question: l'embolie graisseuse du poumon peut-elle se faire sans déclencher des troubles apparents de la fonction respiratoire?

Lorsqu'on se base sur le point de vue physiologique, que les cellules alvéolaires sont à même de digérer la graisse embourbée dans les contingents parenchymateux, on peut soutenir pareille idée. Cela dépend naturellement de la masse de graisses déposée, cela dépend aussi du pouvoir digestif momentané de la lipodiérèse. Et, dans ce domaine, nous pouvons être en présence d'une insuffisance physiologique d'abord, puis pathologique dans la suite.

La constitution pulmonaire individuelle, dans le cas spécial, entre certainement en ligne de compte, pour autant qu'elle soit normale, afin de parer au premier choc. Il est fort probable qu'une certaine quantité d'emboles graisseux puisse être exterminée. Cela dépendra du coefficient: quantité par rapport à la qualité du pouvoir exterminateur. Mais au fur et à mesure que la quantité augmente, du moins brusquement, la qualité exterminatrice doit faiblir. Ainsi, dans ce mécanisme, le nombre pèsera lourdement sur les moyens de défense de l'organisme.

Puis il faut tenir compte d'une complication sérieuse: le passage dans la grande circulation. Car la résistance et le pouvoir d'extermination sont certainement handicapés dès que le parenchyme pulmonaire est accablé dans son second circuit qui a un rôle éminemment nutritif. Viennent ensuite les désordres qui vont de pair dans les grands organes d'importance

vitale. (Cerveau, foie, moëlle, etc.). Il est certain qu'un individu atteint d'une embolie graisseuse qui se fait en circuit fermé (petite circulation) aura plus de chances de réparer les dégats causés. Par contre ces chances diminuent sensiblement chez l'individu dont le trou de Botal est ouvert. Dans la fermeture du Botal réside peut-être pour une part du moins le secret de certaines guérisons.

Mais il ne faut pas négliger, dans tout cela, la réserve de la force cardiaque. Car justement dans un Botal fermé, le cœur droit est soumis à une rude épreuve, le Botal ouvert étant une soupape d'allégement. Soulignons encore ce fait, sans doute, paradoxal: c'est la force cardiaque qui poussera en avant les masses graisseuses dans les systèmes de différents calibres aussi bien de la petite que de la grande circulation, jusqu'à l'obstruction des capillaires. Quant au sort des emboles graisseux dans les cas qui guérissent, NAVILLE nous dit ceci: »Plusieurs auteurs ont cherché ce que devient cette graisse; HALM en a retrouvé les traces dans les poumons et le foie, chez les animaux sacrifiés un mois après l'embolie; avec BERGMANN, il a contesté qu'elle s'élimine en partie par les reins.» BENEKE, ne connaissant pas, à l'époque, les mécanismes de la lipodiérèse a constaté sa saponification et son élimination par phagocytose leucocytaire. Il conclut ainsi à sa résorption par l'organisme et notamment par le foie.

D'après notre documentation sério-radiographique, l'élimination des agglomérats graisseux et de leur cortège d'éléments concomitants doit se faire relativement vite. Mais gardons-nous de vouloir faire des déductions plus ou moins accentuées des phénomènes radio-morphologiques, rapportées à ces mécanismes, quant à la quantité absolue d'emboles graisseux dans le territoire pulmonaire. Nous verrons tout a l'heure que pareilles déductions peuvent nous mener à de graves erreurs. Car dans le phases radio-morphologiques ultérieures, que nous allons vous démontrer, dès maintenant, et qui se distinguent par des signes radio-optiques, de plus en plus raréfiées, l'image roentgénienne purifiée ne correspond pas à l'immensité impressionnante de l'image macro- et microscopique. Nous sommes ici dans le même cas de contradiction, que dans certaines pneumopathies coniotiques. Rappelons dans cet ordre d'idées que dans les silicoses, selon leur caractère physio-pathologique et notamment dans les formes miliaires, la récolte anatomo-pathologique dépasse de loin ce que nous avons déduit quantitativement d'après les reflets radio-morphologiques!

L'examen radiologique de notre malade, *24 heures* après l'apparition du coma, a donné lieu aux constatations suivantes:

L'image d'ensemble a changé, de fond en comble (Fig. 3). Les grands foyers agglomérés ont disparu. Le style de base rappelle celui d'une exsudation acineuse et interstitielle »peinte à l'aquarelle», placé sur un emphysème général, des deux plages pulmonaires. La disposition de ces

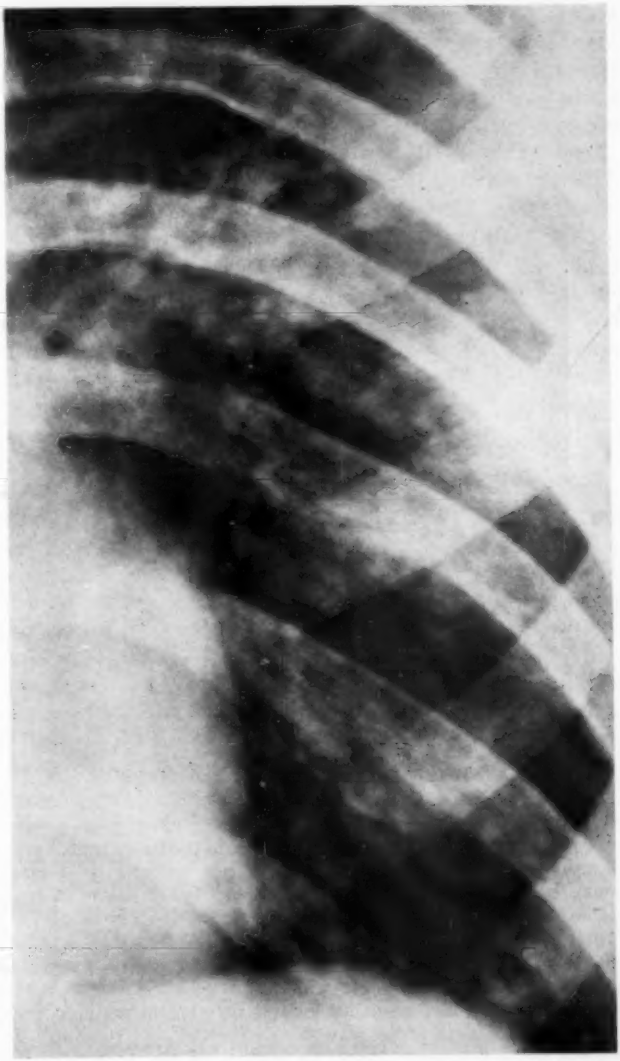

Fig. 3. Détails dans la portion parahilaire sup. et supéro-moyenne gauche. Voyez aussi la dilatation du ventricule gauche.

La radiographie du thorax révèle, dans la seconde phase (24 heures après l'apparition du coma) un style presque exclusivement atélecto-exsudatif (peint à l'aquarelle). C'est la phase de la confluence des foyers acino-exsudatifs et interstitiels.

Pour la première fois l'on constate, à ce moment, l'accroissement de l'ombre cardiaque, avant tout vers la gauche.

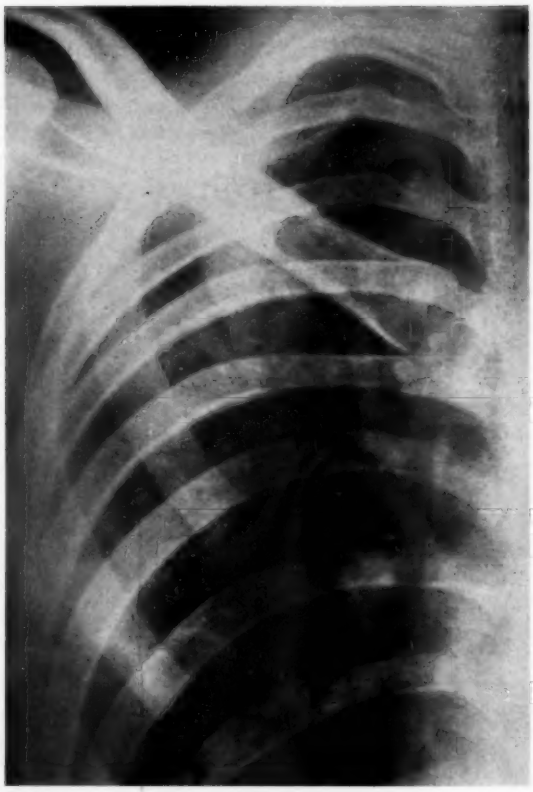

Fig. 4. Poumon supérieur droit.

Radio-morphologiquement, nous nous trouvons, le troisième jour, après l'apparition du coma, devant le tableau suivant: Changement profond de l'image précédente (deuxième jour). Le style exsudatif »peint à l'aquarelle» est balayé et remplacé par un très fin semis de petits foyers folliculo-étoilés, de disposition granulique, à peine visible à cause de l'emphysème qui persiste.

La base anatomo-pathologique de cette architecture radiomorphologique est la suivante: tout le poumon présente un oedème intra-alvéolaire et interstitiel avec des hémorragies qui empêchent l'aération alvéolaire. Un alvéole sur cinq prend part à la respiration. Les alvéoles aérés présentent un emphysème aigu vicariant. Les capillaires sont oblitérés par de très grosses masses de graisse. A de rares endroits il y a même *des embolisations par tissu médullaire.* (Prof. RUTISHAUSER.)

foyers est presque symétrique. A droite, le hile est plus dégagé qu'à gauche; cependant les deux racines sont »laiteuses», homogènement, à la suite de la dilatation des artères pulmonaires, dont les ramifications,

également augmentées, se laissent aisément relancer jusque dans les parties sousspariétales et susphréniques malgré l'emphysème intense.

La zone dorsale supérieure droite, infiltrée de façon plus homogène, est délimitée, vers le bas, par un »coup de faux» scissural. Dans la portion sus-diaphragmatique centrale droite, l'on constate, dès maintenant, un feston qui se prolonge dans un épanchement scissural homogène en »lame de couteau» d'envergure moyenne. Nous ne voyons pas d'épanchement dans les culs-de-sacs (comparez le procès-verbal de l'autopsie qui fait mention de sang liquide dans les deux plèvres et dont, du moins intra vitam, la radiographie n'a pas relevé de traces!). Mais fait spécialement à noter, dans ce tableau radio-morphologique *le cœur accuse, maintenant, une dilatation plutôt moyenne à droite, plus marquée à gauche.* L'amplitude des contractions cardiaques est nettement diminuée. Tachycardie. Cliniquement: état comateux inchangé, lipémie, et lipurie. Ces deux derniers faits expliquent la diminution des dépôts graisseux agglomérés dans le poumon. Il y a eu transport dans les centres éloignées après l'épuisement de l'avalanche.

Le *troisième jour* les modifications radiomorphologiques du territoire pulmonaire *semblent* entièrement balayées. La seule chose frappante est l'emphysème général. Mais un œil averti, se servant de la loupe, constatera dans les deux poumons, *surtout dans les portions sous-domiales et sousspariétales supérieures, de petits foyers étoilés en véritable constellation folliculaire miniature*, dans un style granulique frappant. (Fig. 4.) Ces foyers ressortent spécialement dans les segments supérieurs et supéro-moyens parce que là ils sont moins »purgés» par l'emphysème. Seul reste l'épanchement scissural susphrénique droit qui est, comme nous le savons maintenant par les données nécropsiques, un contingent hémorragique en rapport avec la rupture de la plèvre médiastinale.

Changement également dans le domaine cardio-vasculaire. Les hiles ont repris un aspect normal; le dessin vasculaire, très prononcé par la dilatation du réseau est, à nouveau, normal et le cœur a recouvré ses dimensions habituelles. L'amplitude de ses contractions est cependant des plus faibles.

Cliniquement tableau inchangé! Cet examen correspond à un status de 7 heures ante mortem. Il faut donc admettre que les données relevées par l'autopsie, correspondront, dans une large mesure, aux reflets radio-optiques des lésions constatées.

Voici le procès-verbal de l'autopsie, faite par le Professeur NAVILLE (7344/1947):

Tête: petites suffusions épicraniennes au sommet du front à droite. Calotte mince, mais normale. R.d.p. aux sinus longitudinaux et à la dure-mère sur ses deux faces. Circonvolutions rosées mais sans œdème. Ponction calleuse blanche. Un peu de sang sur la base au-dessus de l'orbite gauche et à la pointe de la fosse temporale gauche. Pas de fracture de la base du crâne.

Cerveau: Les vaisseaux de la base sont tout à fait normaux. Très nombreuses microhémorragies comme des têtes d'épingles dans toute la surface blanche et l'écorce du cervelet, confluentes par places, formant de petits foyers de contusions comme des petits pois en plusieurs endroits dans les deux hémisphères (il y en a plusieurs centaines). Mêmes très nombreuses microhémorragies à toutes les coupes de la protubérance et dans toute sa substance, le bulbe seul n'en ayant pas. La pie-mère est très mince et s'enlève bien partout. Pas de foyers de contusion corticale nulle part. Le corps calleux est par endroits farci de microhémorragies. R. d. p. au plexus choroïde, glande pinéale. Les coupes vertico-transversales du cerveau montrent partout dans la substance blanche et en moindre degré dans les ganglions centraux d'innombrables microhémorragies; dans l'écorce ce sont des points roses pâles.

Cavité thoracique: diaphragme en place. Graisse jaunâtre de 0.5 cm. d'épaisseur. Sternum en carène avec des côtes légèrement proéminentes à gauche et face interne normale, sauf des restes du thymus peu abondants. La plèvre gauche contient 200 cc. de sang très liquide, de couleur sale, sans aucun caillot, paraissant dilué et pouvant provenir d'une déchirure de la plèvre située près du trajet inférieur de l'œsophage et qui communique avec des tissus remplis d'une sérosité sanglante de même consistance.

Poumon gauche: 700 gr. Adhérences entre les deux lobes; tous deux sont couverts d'innombrables pétéchies sur une surface rosée au lobe supérieur qui est assez mou et aéré, sur une surface bleu-âtre au lobe inférieur qui est très distendu. Le hile montre des bronches rouges, humides, mais sans mucosité, ni spume. Pas de ganglions au niveau du hile. Rien de spécial aux gros vaisseaux. La coupe montre un sommet sans cicatrice, un lobe supérieur clair, rosé, sans liquide à la pression, un lobe inférieur œdémacié et congestionné sans aucun noyau spécial.

Poumon droit: exactement les mêmes pétéchies partout sur un fond rosé aux deux lobes supérieurs et violet à l'inférieur. Bronches comme à gauche, vaisseaux normaux. A la coupe: la surface est claire dans les deux lobes supérieurs, luisants, mais ne donnant pas du suc au raclage et montrant de très petits noyaux hémorragiques dans la profondeur. Le lobe inférieur est beaucoup plus humide avec de l'œdème. Poids: 770 gr.

Péricarde: vide.

Cœur: 330 gr. Cœur avec passablement de trainées laiteuses. Les mitrales et tricuspides tiennent l'eau; les sigmoïdes également. *On voit d'emblée que le trou de Botal est ouvert et largement perméable pour une sonde ordinaire.* L'oreillette droite est assez grande. Le ventricule droit, son muscle et la tricuspide ne montrent rien de particulier, de même que le début de la pulmonaire. L'oreillette gauche est un peu nacrée, de dimension plutôt petite; le muscle mesure 13 mm. d'épaisseur contre 5 mm. à droite. Les cordages de la mitrale sont nombreux et plutôt courts; il y a beaucoup

le faisceaux musculaires pariétaux. La valvule est normale, mais il n'y a pas mal de traînées blanches à l'insertion de ses cordages et sur la face interne de tout le ventricule. L'aorte mesure 60 mm. de circonférence contre 70 mm. à la pulmonaire. La coronaire gauche est petite et normale; les nids aussi. La coronaire droite est normale mais large. La coupe du myocarde paraît un peu pâle, mais normale, sans qu'on y voie de petits points hémorragiques. R. d. p. de l'aorte au niveau de la crosse, par contre elle est entourée plus bas d'un tissu hémorragique jusqu'au diaphragme.

Cavité abdominale: Vessie pleine remontant à 8 cm. au-dessus de la symphyse. R.d.p. au petit bassin, appendice, intestins épiploon. Tout le gros intestin depuis le caecum contient des matières assez dures sur tout son parcours. Pas de ganglions dans l'épiploon, mais dans le mésentère on en palpe en assez grand nombre qui sont rosés à la coupe.

Rate: 180 gr. adhérente au diaphragme, ferme, un peu frippée à sa surface.

Surrénale gauche: petite, allongée, mince de couleur ocre peu apparente. La droite d'apparence normale avec une large médullaire, une fasciculaire jaune clair, assez mince, mais large.

Rein gauche: 125 gr. Avec une écorce assez congestionnée et un liseré de vasodilatation en haut des pyramides, probablement des microhémorrhagies dans l'écorce. Consistance banale, bassinet normal. Décortication facile.

Rein droit: 125 gr. normal sauf traînées rouges verticales; dans l'écorce des vasodilatations et microhémorragies. Duodénum jaunâtre. Voies biliaires perméables. Pylore normal. Estomac jaunâtre avec beaucoup de microhémorrhagies un peu partout et autour du cardia où les tissus se déchirent facilement. Pancréas très volumineux partout et un peu violacé.

Foie: 1,350 gr. La vésicule contient beaucoup de bile, très foncée, brunâtre. La surface du foie est un peu violacée. A la coupe, le tissu est un peu gris-jaunâtre; il est friable et ne contient pas de sang.

Vessie: jaunâtre, contient 250 cc. d'urine foncée. Rien de spécial dans la région prostatique et testiculaire.

Aorte descendante normale.

Examens microscopiques:

Poumons: Tout le poumon présente un œdème intra-alvéolaire et interstitiel avec des hémorragies qui empêchent l'aération alvéolaire. Un alvéole sur cinq prend part à la respiration. Les alvéoles aérés présentent un emphysème aigu vicariant. Les capillaires sont oblitérés par de très grosses masses de graisse. A de rares endroits, il y a même des embolisations par tissu médullaire. Rarement nous avons vu des embolies aussi massives. Mentionnons une étroitesse relative des grands embranchements des artères et des veines, et même des bronches. Diagnostic: œdème aigu, hémorragique des poumons par embolies graisseuses massives.

Reins: beaucoup de petits îlots de fibrose et de glomérules soudés aux capsules. Quelques microhémorragies. *Foie:* légère fibrose des espaces portes, pas de dégénérescence graisseuse. *Pancréas:* Il paraît y avoir une surcharge graisseuse de nombreuses cellules. *Cervelet:* Innombrables microhémorragies. Dans l'une on voit de nombreux polynucléaires.

Cœur: quelques microhémorragies. *Surrénale:* normale. ***Embolies graisseuses:*** très nombreuses dans les poumons, glomérule des reins, cervelet, rares dans le cœur, surrénale et foie.

Il s'agit en résumé d'un jeune homme très maigre, de couleur légèrement jaune partout. Dans l'état antérieur des organes, nous relevons la persistance du trou de Botal dans le cœur présentant aussi quelques traînées laiteuses à sa surface, avec une aorte assez petite (60 mm. contre 70 à la pulmonaire). La rate pesait 190 gr. Les surrénales étaient peu colorées. Les autres organes étaient normaux, sauf légère sclérose rénale et pulmonaire.

L'accident a provoqué des contusions superficielles à divers endroits du corps, du nez, au menton et à différents endroits de la face au côté droit.

Comme lésion de profondeur, il y avait *fracture totale du milieu du fémur gauche avec nombreux et grossiers déplacements.* Il y avait en outre une rupture de la plèvre entourant le médiastin postérieur à gauche avec un fuseau de suffusions hémorragiques entourant la moitié inférieure de l'aorte et de l'œsophage, et qui pourraient être responsables de l'épanchement sanguin constaté dans les deux plèvres. On voyait en outre des microhémorragies dans les deux reins.

Les innombrables petites hémorragies constatées dans toutes les parties du cerveau ne paraissent pas être en relation avec les lésions de surface de la tête, mais avec une embolie graisseuse de la grande circulation provenant de la fracture du fémur et favorisée par l'ouverture du trou de Botal. Les innombrables petites hémorragies des deux poumons provenaient de la même origine, et le microscope a en effet montré de très *nombreuses embolies graisseuses dans les deux circulations.*

Il est intéressant de revenir encore une fois sur la radiomorphologie pulmonaire quelques heures avant la mort. Nous voudrions attirer l'attention sur l'état de discordance entre l'image radiologique et la récolte de détails histologiques. Le pathologue, dans son résumé des altérations microscopiques, insiste sur le fait qu'il »a rarement vu des embolies aussi massives». Il mentionne en outre la présence de contingents embolisants de source médullaire et souligne *l'étroitesse relative des grands embranchements des artères et des veines, et même des bronches.*

Dans l'ensemble des données radiologiques, nous avons été encore frappés de la raréfaction du dessin *physiologique* à côté de la »purge» patho-morphologique. L'emphysème, au moins en ce qui concerne la raréfaction du dessin broncho-vasculaire, ne peut pas être incriminée entièrement.

D'autre part, nous avons été frappés du retour à la norme de l'ombre cardio-vasculaire. Ceci ne serait-il pas à mettre sur le compte d'un phénomène pathologique? Dans cette phase terminale de l'embolie graisseuse

quel serait le mécanisme qui provoque l'étroitesse des artères, des veines et des bronches et le rétrécissement des cavités cardiaques? Serait-ce un réflexe central du désordre cérébral, serait-ce un réflexe local de Binet et Lurstein?

Conclusions

Dans la sério-radiographie de cette embolie graisseuse, à partir de l'apparition du coma, nous pouvons distinguer trois phases radiomorphologiques:

a) *Première phase, saisie à la vingt-sixième minute:*

Elle est la phase agglomérée où l'on distingue deux plans: Celui des images stylistiques, ressortissant du bourrage graisseux et médullaire des canaux, grands, moyens et petits de la petite circulation, et celui d'éléments embolisants (foyers folliculo-étoilés) dans la grande circulation. Nous sommes en présence de l'étape agglomérée-miliaire. Fait à noter: l'ombre cardiaque n'est pas modifiée. (Fig. 1.)

b) *Deuxième phase, 24 heures après l'apparition du coma:*

Le tableau morphologique d'ensemble est caractérisé par une constellation exsudative. Les grands foyers agglomérés ont disparu. Il y a, dès maintenant, confluence de foyers acineux et interstitiels, logés dans la petite et la grande circulation. Pour la première fois, nous voyons l'accroissement de l'ombre cardiaque, dont l'amplitude contractionnelle est nettement diminuée. Les plans homogènes (aspects laiteux), aussi bien dans le parenchyme périphérique que dans les parages hilaires, et même dans la projection hilaire proprement dite, doivent provenir de phénomènes atélecto-exsudatifs, issus d'une part de troubles de la circulation (œdème), d'autre part des troubles de l'aération (Fig. 3).

On pourrait appeler cette phase, à cause des éléments morphologiques qui la constituent: étape atélecto-exsudative et miliaire. Enfin la

c) *Troisième phase, 3 jours après l'apparition du coma*, est d'une constellation granulique pure, mais *difficile à déceler*. Nous sommes en présence d'une raréfaction stupéfiante du dessin pathologique. Mais méfions-nous! A la loupe et à l'aide d'un négatoscope parfait, nous découvrons, dispersés sur tout le territoire pulmonaire, un semis de petits foyers stellaires à titre radio-absorbant extrêmement réduit.

Dans cette phase le cœur frappe par sa petite taille. *Il a fait, au cours des trois phases, un mouvement d'accordéon.*

Comment se peut-il que l'image radiologique nous livre si peu de prises dans le diagnostic de l'embolie graisseuse lors de sa période d'état la plus alarmante. Que dire, en qualité de radiomorphologiste, devant pareil tableau déconcertant? (Fig. 4.)

Nous ne pouvons que faire la conclusion suivante: il y a certainement dans le parenchyme pulmonaire, selon l'intensité quantitative et qualitative, des éléments, provenant d'une embolie graisseuse, que nous ne verrons pas grâce au titre peu modificateur de la gamme radio-optique de ces éléments. Il faut donc observer une réserve, des plus strictes, quant à nos analyses non seulement concernant le nombre des éléments en jeu mais encore concernant la question: est-ce qu'il y a embolie graisseuse dans le territoire pleuro-pulmonaire ou non?

Dorénavant notre attention doit être éveillée. Il faut rechercher, avec tous les moyens de précision à notre disposition, la moindre trace d'une constellation miliaire; car comme nous venons de voir, celle-ci, quoique visible exclusivement dans les régions supérieures et sous-pariétales, peut nous livrer la clef d'un processus intense disséminé sur la totalité de la surface pulmonaire.

Dans cet ordre d'idées, la signalisation intense des deux premières phases a été peut-être très exceptionnelle, dans notre cas. La raison, pour laquelle nous nous trouvons devant cette exception, nous échappe. Nous avons émis une hypothèse plausible, en pensant à la mobilisation de la masse inorganique; mais aussi longtemps que l'anatomie pathologique ne puisse nous donner des explications exemptes de toute critique, cette hypothèse est caduque. Car nous voyons les moindres altérations miliaires se signaler, d'une part avec précision et d'autre part avec précocité, lorsque la lésion de fond est de nature spécialement toxique; ce sont justement les processus irritatifs sur le plan toxique, qui appellent très tôt, à la migration et à la concentration, les sels minéraux et les halogènes. Or, nous nous trouvons dans l'embolie graisseuse devant un phénomène irritatif, avant tout sur le plan mécanique.

Les éléments radio-pathologiques que nous relevons, si nous avons la chance de les saisir ou de les reconnaître, ont seulement une signification pathognomonique, lorsqu'ils concordent avec le *tableau clinique général*. Trouvés au hasard on intentionnellement, lors d'une fracture ou d'une contusion, lors d'une éclampsie ou d'un tétanos, ils doivent cependant nous inciter à penser, à priori, à des éléments provenant d'une embolie graisseuse du poumon, *même si, sur le plan pulmonaire, il y a absence d'un désordre fonctionnel.*

RÉSUMÉ

Le mécanisme physio-pathologique de l'embolie graisseuse, au niveau des deux plans circulatoires, doit se faire successivement: 1) par l'arrivée des masses graisseuses et médullaires dans les grands troncs vasculaires, hilaires et parahilaires, où se fait le premier stockage; 2) par la mobilisation ultérieure de ces masses, grâce à la pression venant du cœur et des mouvements respiratoires; 3) par l'avance des emboles au-delà des vaisseaux d'un calibre de 4 mm jusque dans le système capillaire. Si le Botal est ouvert, l'avance dans les deux circulations doit être parallèle.

Radiologiquement les différentes phases de cette avance sont difficiles à classer. Car les deux premières, quoique fort alarmantes du point de vue morphologique, n'ont, *à première vue*, aucun style caractéristique. Elles pourraient donc donner lieu, (admettons que le diagnostic clinique d'embolie graisseuse ne soit posé), à des interprétations fausses; d'autant plus que les effets locaux, dus à l'embolie, peuvent, selon les conditions données et selon les circonstances, être plus ou moins vite réparés, si le Botal est fermé.

La présence de foyers étoilés ou folliculaires, que nous avons placés d'emblée, physio-pathologiquement, dans la grande circulation, ne peut pas servir de critère pour le diagnostic d'un Botal perméable. La troisième phase, malgré son caractère miliaire, est si peu frappante (manque de radio-absorption) qu'on risque de ne pas la saisir.

Ces trois phases se classent, *radio-morphologiquement*, par les caractères suivants: la première, par ses grands foyers agglomérés à côté de foyers acino-miliaires, *sans* modification de l'ombre du cœur; la seconde, par son caractère spécialement miliaire du type atéléctasique et exsudatif, *avec* modification de l'ombre cardiaque (augmentation vers la droite, mais spécialement vers la gauche); la troisième, par une purge frappante des éléments précités et par la persistance d'un dessin étoilé et folliculaire (style granulique) généralisé *sans* modification de l'ombre cardiaque.

Quant à cette troisième et dernière phase, il est frappant que l'image radio-morphologique si pauvre soit en contradiction avec la moisson anatomo-pathologique si abondante. En voyant cette pénurie d'éléments radioabsorbants vis-à-vis d'un tableau anatomique, si gravement chargé (œdème, hyperémie, atéléctase, emphysème, emboles graisseux et médullaires, modifications capillaires intenses), on est consterné de la fragilité de notre outillage enregistrant.

SUMMARY

The physio-pathological mechanism of the fatty emboly, in the two circulatory systems of the lung, takes place 1) by the arrival of fatty and medullary masses in the vascular, hilar and parahilar vessels where the first stockage takes place; 2) by the ulterior mobilization of these masses due to the heart and breathing movements; 3) by the advance of the emboli beyond the vessels of 4 mm diameter into the capillary system. If the Botal orifice is open, the advance is parallel in the two circulatory systems.

Roentgenologically the different phases of this advance are difficult to classify; the the first and second phase, though alarming from a morphological point of view, have, at first sight, no caracteristic style. Therefore they could give cause (admitting that the diagnosis of fatty emboly has not been established) for false interpretations, especially as local effects, due to the emboly, may, according to the circumstances, be more or less quickly repaired if the Botal orifice is closed.

The presence of star-shaped or follicular foci, that we admit being, physio-pathologically, in the large circulatory system, cannot be a criterion for a permeable Botal orifice. The third phase, in spite of its miliary characteristic, is so little striking (absence of radio-absorption) that it risks not being observed.

The three phases may radio-morphologically be classified by the following characteristics: The first one by its large agglomerated foci, beside acino-miliary foci, *without* modification of the shadow of the heart; the second one, by its miliary aspect, of the atelectatic and exudate type, *with* modification of the heart shadow; the third one, by a striking disappearance of the above elements and the persistance of a generalized star-shaped and follicular design (granulic style) *without* modification of the heart shadow.

The contradiction between the radio-morphological image of the third phase, so poor in elements, and the abundant anatomo-pathological findings (edema, hyperemia, atelectasis, emphysema, fatty and medullar emboli, intense capillary modifications) is striking.

ZUSAMMENFASSUNG

Auf Grund physio-pathologischer Untersuchungen und serio-radiographischer Kontrollen spielt sich die Fettembolie der Lunge folgendermassen ab: 1) Zunächst Auftreten der Fett- und Markmassen in den grossen parahilären Ästen des kleinen Kreislaufes; hier findet, trotz des Nachschubs, eine Art Speicherung statt. 2) Infolge des Drucks der Herzpumpe und des Atemmechanismus werden diese Massen in die kleineren Äste weitergepresst. 3) Übertritt der Massen über die 4 mm Gefässkalibergrenze in das Kapillarsystem. Ist der Ductus Botalli offen so geht die unter 2) and 3) erfolgte Weiterbeförderung im kleinen und grossen Kreislaufsystem parallel.

Röntgenmorphologisch sind die zweite und die dritte Phase nicht leicht zu erfassen und zu differenzieren. Infolgedessen können sie, zumal die klinische Diagnose einer eventuellen Fettembolie nicht gestellt ist, zu falschen Interpretationen Anlass geben. Die sternförmigen oder follikulären Herdschatten, die wir von vornherein als Fett- und Markdepots (mit ihren Sekundärerscheinungen) in den grossen Kreislauf eingesetzt haben, sind nicht als vollwertige Indizien eines offenen Ductus Botalli anzusehen. Besonders die Herde der dritten Röntgenphase (reine miliare Konstellation) sind schwach strahlenabsorbierend und gehen ausserdem in dem für diese Phase typischen Emphysem unter.

Trotz diese Schwierigkeiten können wir *bei genauer Lupenbetrachtung* für jede der drei Phasen folgende röntgen-morphologische Merkmale aufstellen. Erste Phase: Gleichzeitiges Auftreten von sehr grossen Ballungen und kleinen azinös-miliaren Herdschatten, *ohne* Veränderung des Herzschattens. Zweite Phase: Fast rein miliarer Typus der Herde von exsudativ-atelektatischem Charakter, kombiniert mit einer Erweiterung des linken und des rechten Herzens. Dritte Phase: Auffällige Säuberung der Lungenfelder von den grösseren Herden. Bestehenbleiben der kleinkalibrigen miliaren Aussaat, die sehr wenig röntgenabsorbierend ist. Der Herzschatten ist zur normalen Grösse zurückgekehrt. Das Frappante an dieser Phase ist die Diskordanz zwischen dem relatif armen Röntgenbild und dem überaus schweren anatomisch-pathologischen Befund (Ödem, Hyperämie, Atelektase, Emphysem; erhebliches Vorhandensein von Fett- und Markembolien, schwere Veränderungen der Kapillaren).

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CASE OF SARCOMA IN IRRADIATED MANDIBLE[1]

by

Sigvard Kaae and *Mogens Glahn*

Sarcoma arising as a sequela of irradiation of bone is an uncommon condition. CAHAN, WOODARD, HIGINBOTHAM, STEWART & COLEY have in 1948 collected seventeen cases from medical writings. Besides this they report eleven cases of their own from Memorial Hospital, New York, making a total of twenty-eight cases. MARTLAND'S ten cases of osteogenic sarcoma in radium-dial painters can be mentioned in this connection.

The initial lesions treated by roentgen or radium were tuberculosis, benign giant-cell tumors, bone cysts and other benign diseases. Two cases were irradiated postoperatively for carcinoma of the breast. The treatment used was in most of the cases roentgen rays. Radium, radium-emanation or a combination of roentgen and radium was used in three cases.

The roentgen doses were large. In nine of the cases reported by CAHAN et al. the depth doses in the bones were calculated to over 3,000 r or even more.

WOODARD & COLEY (1947) found that bone-doses larger than 3,000 r usually cause permanent damage to the regenerative capacity of normal bone. Doses of more than 5,000 r were likely to cause complete devitalisation of adult bone, but the bones of children survived much larger doses. On that account CAHAN et al. suggest that the development of osteogenic sarcoma in irradiated bone is analogous to the development of leukemia in marrow or epithelioma in the skin that has undergone severe atrophy from irradiation.

The latent period, calculated from the date of the last roentgen or radium treatment prior to the onset of the clinically determinable sarcomatous change was three to twenty-two years.

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The sarcomas were in most cases located in long bones. In one case only, the mandible was involved.

Histologically the sarcomas proved to be various types of osteogenic sarcoma, in some cases with a preponderance of cartilaginous elements.

The most prominent symptom was a rather sudden onset of steady and progressively increasing pain in the area. The second most consistent symptom was swelling with or without dysfunction.

CAHAN et al. emphasize that when a patient returns with complaints of pain, with or without swelling, in an area, which had been irradiated five or more years previously, malignant change should be suspected immediately.

As sarcoma arising in irradiated bones are uncommon with only one case reported in Scandinavian literature (NØRGAARD), and CAHAN et al. have reported only one case in the mandible, we shall account for a case of sarcoma in the mandible arising thirteen years after treatment of a gingival carcinoma with radium.

Case. Male, 62 years old.

13½ years previously the patient was treated for a carcinoma in the gingiva of the left mandible. Histologically the tumor was diagnosed as a *carcinoma planocellulare parakeratoticum* (Fig. 1).

Treatment: 1st part. Thorough *electrocoagulation* of the tumor. *Radium* in brass tubes, 30 mg in the coagulated area, 10 mg in the place of the 3rd molar (which had been extracted beforehand), 10 mg on the top of the big tube, in all 50 mg radium, tubes placed in metal-free rubber, fixed by sutures, were removed after 22 hours. *Total dosage: 1,100 mg.-hr.*

2nd part: *Evacuation of the left submaxillar region*, removal of lymph-nodules and submaxillar salivary gland. 4 × 10 mg radium in brass tubes, fixed in the empty region, were removed after 18½ hours. *Total dosage: 740 mg.-hr.* Microscopically no metastases were found in the removed lymph-nodules. The patient was watched for five months after this, and no symptom of remission was found.

13 years after the operations he noticed pain and swelling of the mandible in the area previously involved. A roentgen examination revealed large *destruction and spontaneous fracture* of the left corpus mandibulae (Fig. 2). Microscopically: *Fibrosarcoma and — superficially — carcinoma* as well. (Fig. 3.)

Treatment: Resection of the left half of the mandible together with *dissection* of soft tissue at a respectful distance from the tumor. The postoperative course was uneventful. Microscopically the tumor proved to be a *fibrosarcoma.* (Fig. 4.) No carcinoma was found in the removed tissue.

Epicrisis: A case of fibrosarcoma in the mandible in a 62-year-old male, who 13 years previously had been treated for a carcinoma in the same place with large doses of radium.

Bone sarcoma following irradiation of another malignant disease is — as already remarked — a rare condition, probably because few of the

Fig. 1. Original tumor showing typical carcinoma.

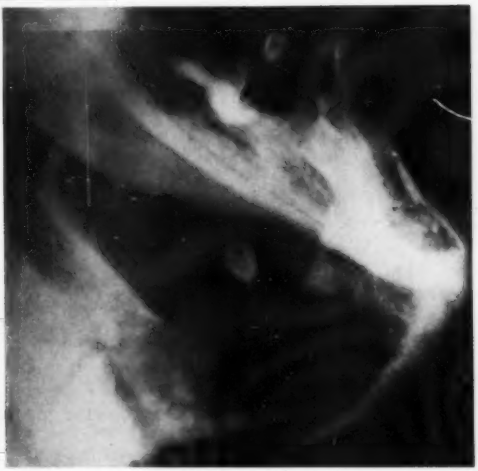

Fig. 2. Roentgen photo of left mandible 13 years after radium-treatment, showing large destruction and spontaneous fracture.

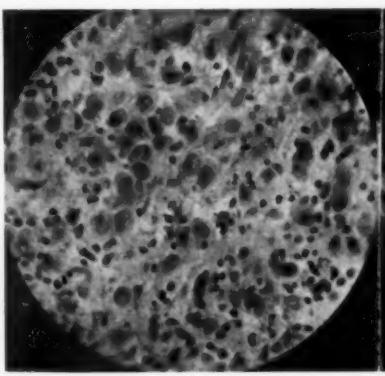

Fig. 3. Section of tumor before operation. Fibrosarcoma with carcinomatous cells.

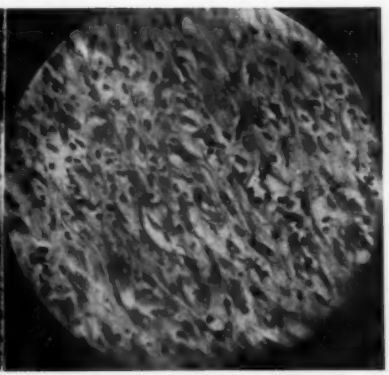

Fig. 4. Section of removed tumor. Fibrosarcoma.

patients survive long enough, and of course we do not believe that the mere possibility of causing bone sarcoma after years can alter the indications for irradiation therapy of malignant diseases in the neighbourhood of bones.

SUMMARY

The authors present a case of sarcoma in the mandible arising 13 years after treatment of a gingival carcinoma with electrocoagulation and radium in the area.

ZUSAMMENFASSUNG

Die Verfasser referieren einen Fall von Fibrosarkom in dem Unterkiefer, entstanden 13 Jahre nachdem ein Carcinoma gingivae in derselben Stelle mit Electrokoagulation und Radium behandelt worden war.

RÉSUMÉ

Les auteurs relatent un cas de sarcome de la mâchoire inférieure survenu 13 ans après le traitement d'un carcinome gingival par électrocoagulation et application de radium dans la même région.

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For the rest of the literature we refer to the bibliography in the first article.

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SOME ASPECTS OF THE USE OF ELECTROKYMOGRAPHY IN CARDIAC INVESTIGATIONS[1]

by

Bruno Engström, Sven Roland Kjellberg, Lars Persson and *Ulf Rudhe*

Roentgen kymography is a method of recording photographically the movement of a roentgen shadow. This can take place either directly or indirectly. In the former case the roentgen rays are allowed to fall on a film after passage through a grid with one or more slits. In the latter, rays affect a photographic paper by means of a photocell or a Geiger-Müller tube coupled to an amplifier. The direct method has for many years been generally in use and it is only very recently that it has found a competitor in the indirect method. SABAT 1911, and GÖTT and ROSENTHAL 1912 were the first to describe the principles of the first-mentioned technique. Great interest has been accorded to it during later years by STUMPF 1928, SCHERF and ZDANSKY 1929, READ 1929, DELHERM, THOYER-ROGAT and FISCHGOLD 1934 and HECKMANN 1937, amongst others.

During the past ten years repeated attempts have been made to register indirectly the movements of the heart. The first report, however, was only published in 1945 by HENNY and BOONE. Owing to the difficulties of producing satisfactory and reliable apparatus no more extensive use has been made of the method and only a few articles have been published by MARCHAL 1946, LIAN and MINOT 1946, CHAMBERLAIN 1947, HENNY, BOONE and CHAMBERLAIN 1947, LUISADA et al. 1948, ELLINGER et al. 1948 and ANDERSSON 1948.

Since it proved impossible with the aid of direct kymography to reproduce the finer details of the course of movements in the different chambers of the heart, one of the present writers (Kjellberg), stimulated by Professor Hugo Laurell's great interest in cardiology, began experiments with electrokymography in 1936. The first tentative experiments

[1] Submitted for publication, May 11, 1949.

were made with an ionisation camera constructed by the Institute of Radiophysics in Stockholm. The results did not correspond to the expectations and it was therefore necessary to try other measures. Attempts were then made with photocells of various types. It soon became apparent that the cells of photo-emission type then available were not suitable since their sensitivity did not correspond to or even approach the wave-lengths of the available screens. Considerably better results were achieved with selenium cells, which were therefore used in the apparatus constructed in 1943. The principle of the apparatus is based on the fact that the variations in current generated in the selenium cells with the movements of the heart are amplified and recorded on an E. C. G. paper simultaneously with the patient's E. C. G. Gradually, however, it was found that the roentgen rays had a deleterious effect on the cells causing a decrease in their sensitivity. When they had been used for some time, it was therefore necessary to replace them. During the war it was impossible to obtain these photocells. We were therefore obliged to interrupt the experiments and to await the new photocells of multiplier type which began to be available on the market. The apparatus now used by us is reconstructed for this type of cell.

It appears justified at the present stage of our experiments to give a general survey of the possibilities of this method in cardiac investigations.

A. The theory, construction and properties of the apparatus

Kymography should immediately and accurately reproduce each change in the position of the cardiac border.

The signal caused by the movements of the cardiac border can, irrespective of the shape of the curve, be described as a total of sine terms with varying frequencies, amplitudes and phase angles. The frequency range is determined on the basis of the following argument: The lowest frequency is presumably that of the pulse, which in extreme cases can be as low as 0.6 c/s, which gives a lower limiting frequency of 0.1 c/s if the phase shift at 0.6 c/s is not to be excessive. The highest observable frequency is determined by the speed of the paper in conjunction with the density of the curve. When 0.01 second corresponds to one millimetre and the line is at times approximately 1 millimetre wide, it can be said that the time for an observable period lies between 0.01 and 0.02 second, corresponding to a frequency of 100 and 50 c/s respectively. Practical experiments have verified the fact that pure sine oscillations can be observed even if their frequency considerably exceeds 100 c/s. On the other hand, a square wave with a frequency of 3 c/s cannot be noticeably affected until the upper limiting frequency falls below 60 c/s and even then the effect is only very slight.

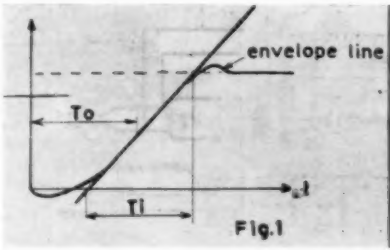


Fig. 1

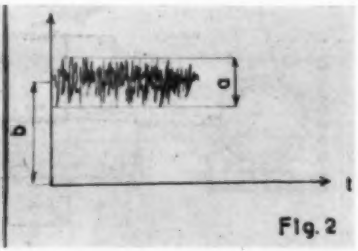


Fig. 2

The time delay to which a signal can be exposed when it passes through a four-terminal network can be calculated according to the following. It is assumed that a sine signal with a frequency that lies relatively far from the possible limiting frequencies of a four-terminal network is suddenly switched on at a time $t = 0$. The appearance of the signal at the output terminals of the four-terminal network is that shown in fig. 1. It is found that $T_i = \frac{\pi}{\omega_0}$ and $T_0 = \frac{da}{d\omega}$ when ω, as is customary, is 2π times the frequency, ω_0 is the limiting angle frequency and a is the phase shift. With the insertion of $\omega_0 = 2\pi \cdot 60$, we obtain $T_i = 1/120$ second.

It is nevertheless unfortunately impossible to fulfil altogether the forementioned requirements. Thus, for example, the roentgen apparatus is driven from the net, which gives rise to considerable hum. Furthermore, at these low illumination intensities, the photocell emits a noise which is also appreciable.

We can assume that roentgen apparatus of different constructions manifest varying percentages of hum, when this percentage is defined as $\frac{a}{b}$ 100 (v. fig. 2).

The hum in a condenser-filtered roentgen apparatus is thus of the same order of magnitude as the cardiac signal at its weakest, whereas the hum from a three-phase apparatus is four or five times greater. The frequency of this hum is 50 c/s and 100 c/s with a 50 c/s net.

The noise is partly dependent on the working voltage of the photocell (photocell: RCA. 931 a), but more especially on the illumination. Fig. 3 shows the noise in

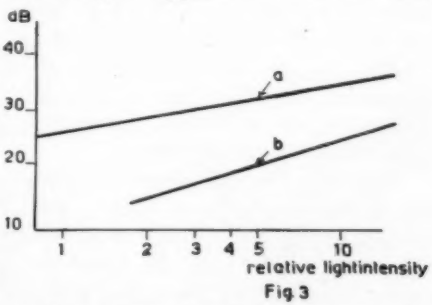
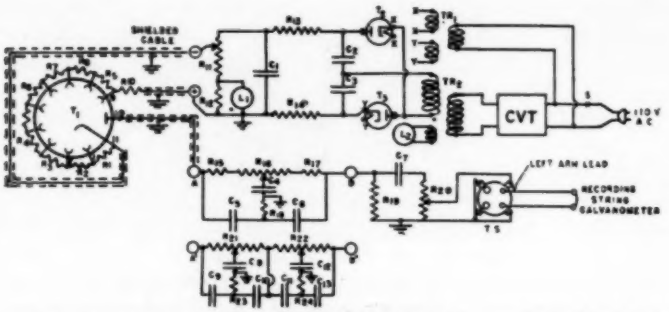


Fig. 3

a. direct current lamp b. roentgen rays.



Schematic wiring diagram of the electrokymograph. R_1 to R_9 = 0.1 megohm, half watt resistors. R_{10} = 50,000 ohms, half watt. R_{11} = 2 watt resistor, approximately 1.7 megohms, adjusted to give output of 1,000 volts to tube network. R_{12} = 150,000 ohms, 2 watt. R_{13} = 0.2 megohm. R_{14} = 0.1 megohm, 2 watt. R_{15}, R_{17} = 10,000 ohms, half watt. R_{16} = 20,000 ohm potentiometer (carbon). R_{18} = 17,500 ohms, quarter watt. R_{19} = 1 megohm, half watt. R_{20} = 10,000 ohm potentiometer (carbon), linear taper. R_{21}, R_{22} = 100,000 ohm potentiometer (carbon), linear taper. R_{23}, R_{24} = 7,000 ohm, quarter watt. C_1 = 2 mfd. 1,500 volt. C_2, C_3 = 1 mfd. 1,000 volt. C_4 = 0.18 mfd. paper. C_5, C_6 = 0.05 mfd. paper. C_7 = 2 mfd. paper. C_8, C_{10} = 0.06 mfd. 400 volt paper. C_9, C_{13}, C_{11}, C_{12} = 0.1 mfd. 400 volt paper. T_1 = RCA 931-A multiplier phototube. T_2, T_3 = 2 X 2 (879) rectifiers. TR_1 = SNC 4P222 dual filament 2.5 volt transformer. TR_2 = SNC 8P186 power transformer 325–0–325 volts. C/T = Sola constant voltage transformer, 301003, 15 watt. L_1 = G. E. three-quarter watt, 125 volt neon lamp. I_1 = 6 volt pilot lamp. $T.S.$ = binding post terminals into which the tips of the electrocardiograph leads are inserted. S = power line switch. The filter between A and B eliminates 120 cycle ripple (full-wave rectified roentgenoscope). The other filter, shown between A_1 and B_1, is used in place of the first when the roentgenoscope is of the self-rectified or half-wave type. Ground connections are indicated by the usual symbol.

Fig. 4. After HENNY, BOONE, CHAMBERLAIN.

the illumination range in question with a suitable photocell voltage. Curve *a* is valid for direct illumination of the photocathode by means of a direct current lamp, and curve *b* is taken with roentgen rays that are allowed to affect the photo-cathode via the fluorescent screen. Curve *a* is in good agreement with the figures given by the manufacturers. In respect of the spectral distribution of the noise, it can be noted that the amplitude depends on the frequency range as Δf^k, where k is a constant somewhat greater than 1. This relationship is valid up to *ca.* 50 c/s. With a greater frequency range, the amplitude is practically independent of the range.

The degree of modulation in the input signal varies appreciably depending on which part of the cardiac wall is being examined and also on the amplitude of the movement. The signal and the noise are of the same order of magnitude.

It can be deduced from the foregoing that the desired frequency range can never be obtained. This is partly because the 50 c/s of the net frequency causes a disturbance and partly because the noise from the photocell is also disturbing. In order to eliminate these disturbances it is necessary to decrease the upper limiting frequency. This, however, involves a distorsion of the signal.

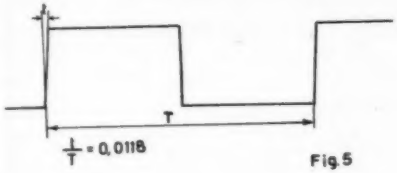


Fig. 5

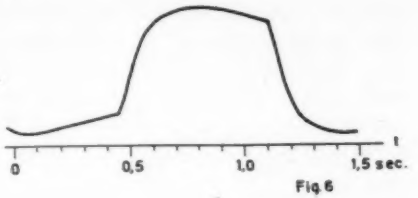


Fig. 6

A study can first be made of Chamberlain's manner of solving these difficulties according to the description of his apparatus in the American Journal of Roentgenology, No. 4. April 1947. His diagrammatic representation is shown in fig. 4.

CHAMBERLAIN in his article recommends a direct coupling of the apparatus to the input terminals on an E. C. G. amplifier.

If the photocell is fed with an artificial signal in the form of a square wave whose amplitude and degree of modulation resemble the signal of cardiac movement (fig. 5), Chamberlain's apparatus gives the following curve (fig. 6). This shows a distinct rounding of the corners at the same time that the horizontal parts slope towards the middle of the curve. The first phenomenon is a sign of too low an upper limiting frequency, whereas the second is due to too high a lower limiting frequency. If, on the other hand, the apparatus is fed with a pure sine-shaped signal and the time delay and attenuation are measured at different frequencies, the curves in fig. 7 are obtained. The lower limiting frequency appears to be approximately 4 c/s, whereas the delay is considerable and — which is more serious — is dependent on the frequency. (The filters were recalculated to the Swedish net frequency of 50 c/s instead of the American 60 c/s.)

The reasons are to be sought in 1) the filter (for diagram v. fig. 8). An interim calculation shows that the complex image attenuation

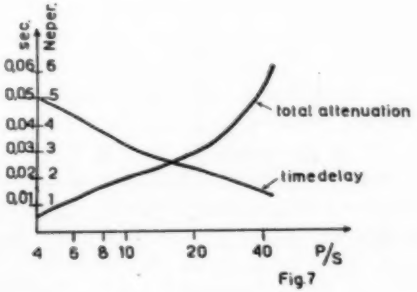


Fig. 7

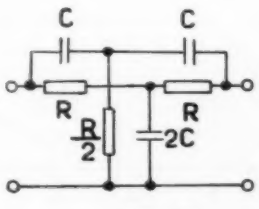


Fig. 8

$b + ja = 2\text{artgh}\sqrt{\omega RC} + j\,2\text{arctg}\sqrt{\omega RC}$ for ωRC less than 1. For ωRC greater than 1, $b = 2\text{arcoth}\sqrt{\omega RC}$. The image impedance is:

$$Z = \sqrt{\frac{R}{j\,2\omega C}}$$

The formulae are completely valid for the filter in fig. 8 which must, however, be considered as an approximation of Chamberlain's wiring diagram. With the value R = 20 k ohm, C = 0.05 μF, we obtain

$$Z = (1 - j)\sqrt{\frac{10^{11}}{\omega}}$$

whose absolute value is $\sqrt{\frac{2 \cdot 10^{11}}{\omega}}$

One end of the filter is directly connected to the last plate in RCA 931 A, whose plate resistance should be in excess of 10 M ohm, whilst its other end is loaded with 10,000 ohm. In order to find the frequency at which the filter is matched, Z = 10,000 is inserted in the equation, giving $\omega = 2 \cdot 10^5$ r/s or just over 300 c/s, thus a frequency entirely outside the actual range. At 3 c/s the image impedance is 100 k ohm. The filter is, however, connected at one end to 10 k ohm and the other to 10 M ohm, the latter being the main source of inconvenience.

By means of the exchange of certain resistances, the coupling can, however, be altered so that matching is achieved. The attenuation curve in fig. 9 is then obtained. The change also implies an improvement in the time delay. The direct current attenuation for this type of filter is, however, considerable.

An appreciably smaller rounding of the corners in the square wave is obtained with the suggested alteration (v. fig. 6).

2) The *E. C. G. amplifier* used with its high lower limiting frequency. If it is assumed that, in order to obviate this fact, an amplifier is built

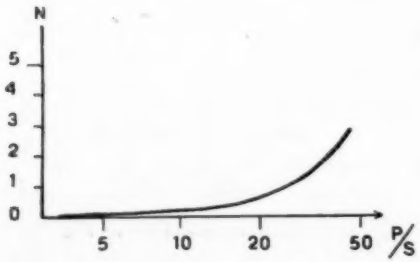


Fig. 9

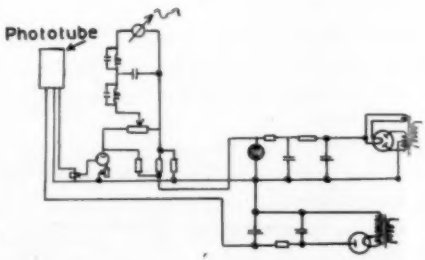


Fig. 10

with a lower limiting frequency of 0.1 s., this implies a time constant of the order of magnitude of 10 seconds. This in turn requires a considerable time for adjustment. The solution therefore lies in a direct current amplifier although this is considerably more difficult to use than one of alternating current type. There are further reasons that warrant the introduction of such an amplifier. If the RC filter is replaced by an LC filter, the attenuation of the pass band range is so low that an amplifier of only one step is necessary. Furthermore, with an LC filter, low attenuation is obtained in practically the entire pass band, whereas the attenuation of the RC filter constantly falls towards a lower frequency. The time delay in this frequency range will be practically independent of the frequency.

Fig. 10 shows the diagram with the changes made and for which the reasons are given in the foregoing. No change was made in the coupling of the photocell but the rectifier was somewhat simplified. The direct current amplifier was calculated in the usual way, as was its rectifier. The apparatus used by the writers is coupled according to this diagram.

It was pointed out in the foregoing that the hum voltage which has its origin in the roentgen apparatus contains two frequencies, *i. e.* 50 c/s and 100 c/s. This makes it necessary to use a filter with two peaks. In the present case an m-derived filter is presumably the most suitable. The two peaks are obtained from two L links, whose dimensions are determined according to the usual formulae.

Since the peak for the lowest disturbance frequency lies at 50 c/s, the upper limiting frequency of the filter must be selected lower than this value. A suitable position from a point of view of matching would be 30 c/s. Nevertheless, the disturbing noise is so considerable here that the frequency range must be still further diminished. The most suitable limiting frequency varies in individual cases. 10 c/s would thus be required for an adequate reproduction of small movements with small contrasts and weak illumination.

According to the filter theory, the image phase shift must approximately follow an arc sine curve up to the limiting frequency. In practice, the effect of the terminal loads is added. In addition, the two links need not necessarily have exactly the same limiting frequency. Thus, within the pass band range, the phase shift can be made to rise fairly linearly towards a point situated between the limiting frequency and the lower peak. The height of the point is π. The time delay and the time T, as well as T_0, are found from the formulae mentioned in the foregoing for this purpose. With a limiting frequency of 15 c/s, $T_1 = 0.03$ second and $T_0 = 0.02$ second can be expected, irrespective of the frequency, in the whole actual range. It is of greater importance that the time delay is independent of the frequency than that it is negligible. This solution thus

implies an improvement in comparison with the time delay in fig. 7. Fig. 11 shows the appearance of the square wave under difficult conditions (cf. fig. 6).

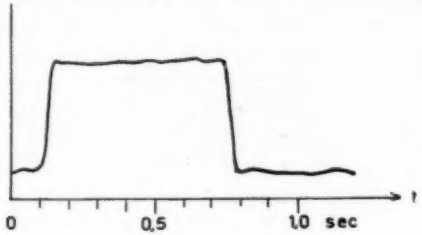


Fig. 11

To sum up, it can be stated that the apparatus designed and used by us faithfully reproduces the course of a movement with the following reservations:

1) All the movements are recorded with a delay of 0.02 second.

2) Very rapid movements with frequencies exceeding 15 c/s are registered as diminished. This does not, however, appear to involve any inconvenience in the recording of the movements of the heart since its frequency rarely reaches this figure with a marked amplitude.

B. The technique used

The patient is placed either on an adjustable stool in the screening stand or in a recumbent position with the photocell in front of him. The photocell is hung so that it can be shifted easily and turned in various planes (v. fig. 12). It is entirely enclosed in lead but in front of the fluoroscopic screen there is a 4×16 mm slit through which the roentgen rays pass. This screen is bent in a V shape, thus allowing a greater light surface. Direct passage of the primary roentgen rays through the photocell is also avoided (v. fig. 13). On exposure this slit is placed so that its longest side is at right angles to the contour to be reproduced and 1/2 to 1/3 of the slit is covered by the cardiac shadow (fig. 14).

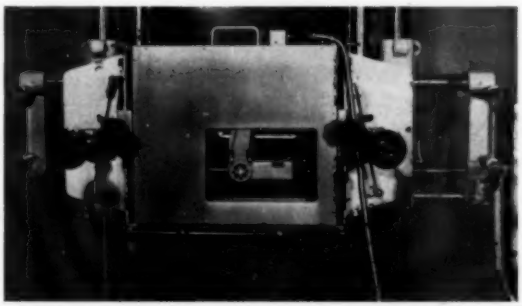


Fig. 12.

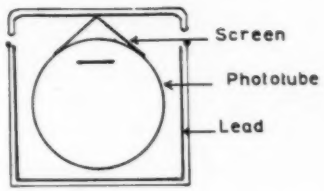


Fig. 13

Fig. 14

Satisfactory records of the curve are usually obtained with an illumination current of 2—4 Ma and a voltage of 50—80 Kv. A relatively high strength of current and a low voltage should be chosen. If the patient is corpulent or the rotation is considerable, the current must be increased to 6 Ma during recording. In order to reduce the variations in the roentgen illumination, we used a condenser apparatus in which the condensers are coupled during screening. The smallest possible aperture is always used so that mainly central rays are utilized.

The patient's E. C. G. (Lead II) is taken simultaneously with the electrokymogram (abbreviated in the following to Ekyg). In order to obviate any disturbances in the E. C. G., all the adjacent metal parts must be isolated so that the patient does not come into direct contact with them. This applies particularly to the foot-plate of the stand. The Ekyg is taken both during respiration and while the patient holds his breath. This is of importance since the appearance of the curves differs somewhat on the two occasions.

For recording of the time and the determination of the simultaneous cardiac phase, use is made — as mentioned earlier — of the patient's E. C. G. This type of curve has been selected for the time correlation since the variability in the E. C. G. is less than for example in the venous pulse, the carotid pulse or the apex thrust, provided that a sufficiently rapidly recording galvanometer is used. We do not consider that it is satisfactory to use, as does Chamberlain, the carotid pulse for the determination of the time factor since it is subject to fairly large variations caused by changes in the elasticity of the vessel walls, the width of the vessels and the rate of the blood flow. Moreover, recording of the carotid pulse is often difficult and distorted curves are not infrequently obtained. Furthermore, it is not suitable to use a pulse curve correlated to the left ventricle, since it is then impossible to determine directly important displacements in times in the action of this chamber.

C. What does the photocell record?

The aperture of the photocell is placed over the cardiac border and is therefore acted upon by rays passing through the cardiac wall and the air-containing lung. Due to variations in the thoracic content, variations in current occur in the cell and these are recorded. These variations are mainly caused by the movements of the cardiac border backwards and forwards in relation to the aperture but also by changes in the thickness of the heart itself and in the air content of the lungs during respiration. The variations in current caused by the changes in thickness are, how-

Fig. 15 a¹ Fig. 15 a²

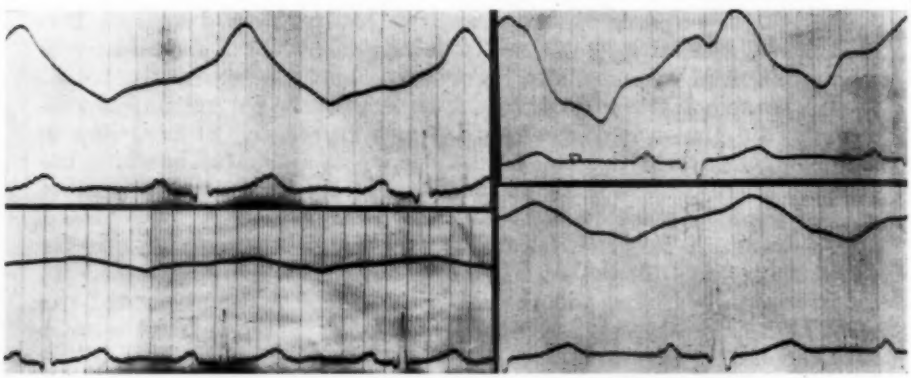


Fig. 15 b¹ Fig. 15 b²

Fig. 15. a. movement of the outline.
b. change in the thickness of the heart.

ever, small in comparison with those caused by the movement of the border and in normal individuals do not amount to more than 1/5 to 1/6 of the latter (v. fig. 15 a—b). This curve is taken by first placing the aperture over the outline of the heart and then shifting it over the heart so that it just impinges over the cardiac shadow. The amplification is constant throughout. It is seen that these changes in thickness are superimposed on the curve. Respiration, on the other hand, gives rise to a wave-shaped rise and fall in the curve, as shown in fig. 16 a—b. This movement is, however, so slow in relation to the pulsations of the heart that no actual distortion of the curve results.

The heart pulsations visible on roentgen examination are composed

Fig. 16 a

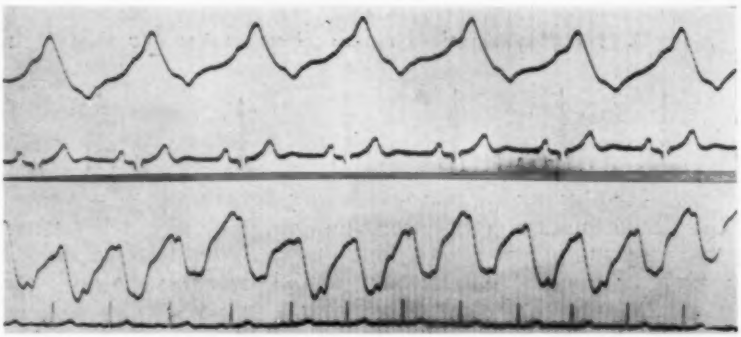


Fig. 16 b

Fig. 16. The effect of respiration on the Ekyg.

of the contraction and relaxation of the different chambers of the heart, the torsion and pendulum movements of the heart and the traction of the vascular stem, all of which are more or less dampened by the pericardial fluid. It is impossible to register each of the movements separately. The amplitude of the so-called pulsations is only an expression of the collective effect of these factors on the movement of the border and not of the actual pulsation of the different chambers of the heart. We have, therefore, when judging the curve, attached less importance to the variations in the size of the peaks in the tracing than to the shape and the times at which the curves change direction and speed. The QRS complex, usually the Q or R wave, is used as the point of departure for the time determination. The E. C. G. apparatus used allows reading of time displacements as small as 1/100 second. The time constant of electrocardiography is 1.5 second. The rate of the electrocardiographic paper can be chosen either as 4 or 10 cm per second.

The apparatus is coupled in such a way that a lateral movement of the cardiac border, as during ventricular diastole, is recorded by a rise in the curve, and a medial movement as a fall.

Since the apparatus is entirely based on the variations in density between the air-bearing lung parenchyma and the cardiac margin, the heart pulsations cannot be recorded when parenchymal densities are situated adjacent to the heart. Moreover, it is often difficult to assess the kymogram in the case of very corpulent subjects owing to the considerable decrease in the signal due to the reduction in the intensity of illumination. The appreciable amplification that must be used in such cases causes the cell noise to be very apparent.

D. Some anatomical data of importance for the placing of the photocell

It is seen from fig. 17 that the lower part of the left outline is composed of the left ventricle which then extends backwards and forms the major part of the posterior lower outline. Immediately above the ventricle — the border is often marked by a small notch — a short, slightly bow-shaped outline comprising the appendage of the left auricle is seen in the frontal projection. The main part of the left auricle is situated posteriorly and lies between the left ventricle and the bifurcation of the trachea. The patient must therefore be rotated to the right in order to record the movements of the outline of the left auricle. Above the auricular appendage, a contour, often slightly bow-shaped, is seen, formed by the pulmonary artery. This vessel has its course obliquely upwards and backwards. It is differentiated above from the aortic shadow by a fairly sharply marked notch in the contour. The right ventricle is situated wholly anteriorly and the greater part of its anterior surface lies against the anterior thoracic wall. Under normal conditions the patient must therefore be rotated considerably to the right in recording the variations in the outline of this cavity of the heart. The lower part of the right border of the heart usually consists entirely of the right auricle. At times, however, the course of the hepatic vein or the inferior vena cava is such that they form the most caudal part of the right border. The right auricle continues backwards and downwards until it reaches the left ventricle. Above the right ventricle is seen a fairly long straight outline, which consists entirely of the superior vena cava. The ascending aorta runs in a curve anteriorly and upwards to the right but never forms a border in normal subjects in the frontal projection. The patient must therefore be turned considerably to the right if the movement of this outline is to be recorded.

E. Some physiological data of importance in the interpretation of the Ekyg

The muscles of the cavities of the heart are considered to consist of four continuous spiral layers which mainly have their origin in the conus arteriosus area and the auriculo-ventricular region and continue downwards towards the apex. At this point they penetrate deeply and contribute to the formation of the interventricular septum. Owing to this spiral construction, all the diameters of the cavities are decreased during ventricular contraction. During contraction, the base is drawn downwards and the large vessels are stretched but the apex is not displaced

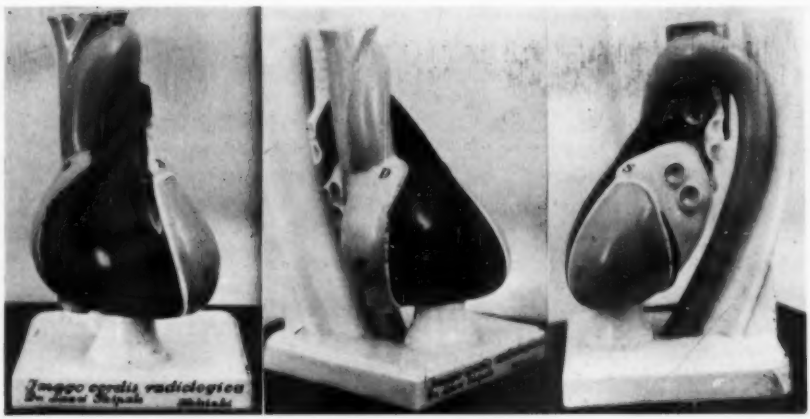
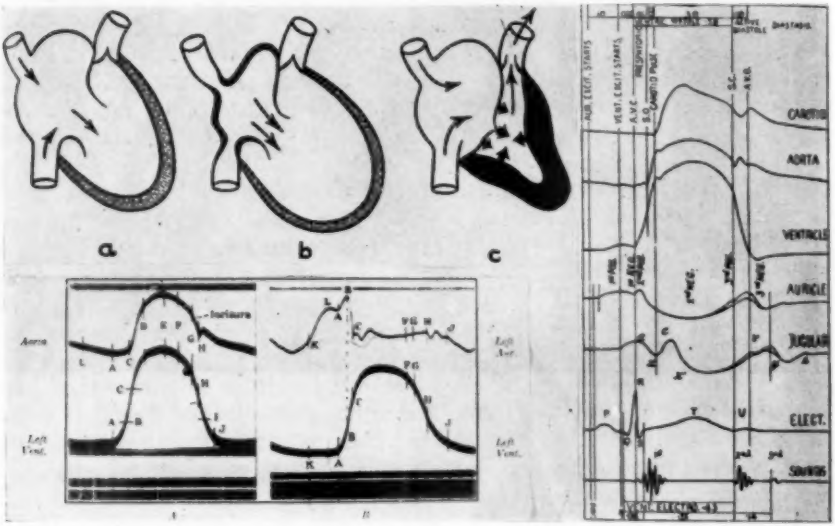


Fig. 17 a Fig. 17 b Fig. 17 c

upwards. The heart rotates at the same time to the right, thereby causing the left ventricle to be rotated somewhat anteriorly.

The heart acts as a pressure and suction pump if this expression is interpreted in the hydro-dynamic sense. During ventricular systole the blood flows from the large veins and is dammed up in the auricle, which acts as a reservoir. During diastole, a large quantity of blood therefore flows fairly slowly through the wide orifice into the ventricle. In ventricular systole, the contraction starts in the apex and then continues upwards towards the base. This can be observed on angiocardiography or still better on an experimental animal if a large quantity of a suitable roentgen-opaque substance — *e. g.* thorotrast — is added to the blood. It can then be seen how the lumen of the ventricle is gradually constricted, starting at the apex. The walls are compressed towards each other and can be said to propel the blood in front of them (v. fig. 18). Immediately below the auriculo-ventricular valves, however, the lumen is not altogether obliterated thus implying that a residue of blood is present at the end of systole. In diastole, on the other hand, the lumen is first dilated in the upper part of the ventricle and the dilatation then continues downwards towards the apex. This arrangement counteracts both the acceleration of the blood flow and the forcing of the blood in a stream towards the apex. The size of the chambers is thus decreased to a considerable extent. The trabeculae presumably have a similar impeding effect on the blood stream. Their task is then to encircle the blood in diastole and to prevent it being propelled downwards towards the apex faster than relaxation can occur. This assumption is supported by the

Fig. 18 Fig. 19



A Fig. 20 B

Fig. 18. The muscular events of the heart. a) Mid-diastole. b) Presystole. c) Systole. The auriculo-ventricular junction is lowered by the ventricular contraction creating an aspiration in the veno-auricular reservoir (after LUISADA).

Fig. 19. After LEWIS.

Fig. 20. Optical pressure curves. A. Ventricle: A beginning of ventricular contraction, C opening of aortic valves, AC isometric contraction, H closure of semilunar valves. G end of ventricular contraction and onset of relaxation. B. Auricle: AB A—V valves are pressed back, BC the base of the ventricles descends, J opening of A—V valves, K Auricular contraction (after WIGGERS).

fact that the trabeculae are most strongly developed caudally, *i. e.* towards the apex, and are diminished upwards and are entirely lacking within the area below the valves. It is in this area that the residual blood is found.

When the stimulation originating in the auricle has reached the ventricle, a contraction of the muscles takes place first and the pressure in the chambers rises (v. fig. 19). This contraction time, also known as isometric contraction, has a duration of approximately 0.05—0.06 second. When the pressure in the ventricles passes the aortic and pulmonary pressure, the semilunar valves are opened and the blood is expelled. Immediately after this, the pressure is still further and fairly rapidly increased — maximum ejection — and is finally decreased towards the

end of the contraction — reduced ejection (v. fig. 20 A). When the pressure in the ventricles falls below that in the aorta and the pulmonary artery respectively, the semilunar valves close. Owing to the reflux of blood that takes place on their closure, a V-shaped notch is shown on the pressure curve, as can be seen in the curve at H. In diastole, the pressure in the ventricles first falls rapidly but then increasingly slowly until auricular systole occurs, when it once more rises somewhat. In the aorta and the pulmonary artery, however, it falls slowly and continuously, owing to the elasticity of the vessel walls (v. fig. 21).

Shortly after the beginning of ventricular contraction, the pressure in the auricle begins to rise rapidly. This is wholly or partly due to a pressing backwards of the auriculo-ventricular valves when the pressure in the ventricles has increased (v. fig. 20 B). At the end of isometric con-

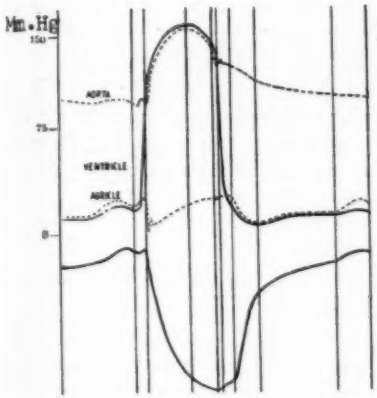


Fig. 21

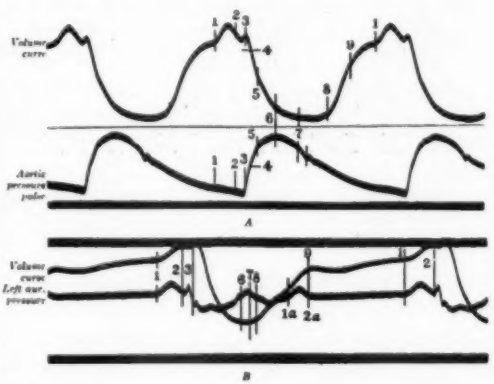


Fig. 22

Fig. 21. Superimposed curves of pressure changes in ventricle (heavy line), aorta (upper dotted line) and auricle (lower dotted line), together with volume curves of ventricles (lower solid line) (after WIGGERS).

Fig. 22. Optical volume and pressure curves. A aortic pressure and ventricular volume curves; B ventricular volume curve and left auricular pressure curve. 2 ventricular systole begins. 3 semilunar valves open, 7 end of ventricular systole, 7—8 isometric relaxation (after WIGGERS).

traction or at the beginning of the ejection period the pressure falls rapidly. This is due to the movement of the ventricular base downwards. As the blood flows in from the large veins, the pressure is once more increased somewhat in the auricle and then falls suddenly during ventricular relaxation. This fall in pressure is conditioned by the opening of the auriculo-ventricular valves and the flowing of the blood down into the

ventricles. The re-filling of the ventricles takes place very rapidly at first but then gradually decreases and finally again rises somewhat in connexion with auricular systole. During the rapid inflow, the pressure falls in the auricle but once more rises during the slow re-filling, *i. e.* diastasis. This rise in pressure is due to the inflow of blood from the veins.

A *change in the volume* of the heart takes place simultaneously with these variations in pressure. With the aid of a cardiometer it can be seen that the volume of the ventricles is only inappreciably altered during isometric contraction whereas there is a distinct decrease with the opening of the semilunar valves. The diminution in volume takes place most rapidly during the first part of systole, maximum ejection, and diminishes towards the end, reduced ejection (v. fig. 22). It is also seen from the curve that no change in volume occurs during the protodiastolic phase and isometric relaxation, whereas it increases rapidly during the rapid inflow. As the ventricles are filled with blood, the increase in volume diminishes and at times entirely ceases before auricular systole. The ventricular volume increases somewhat more during auricular systole. This final increase is, however, in proportion to the length of diastole. Thus, the longer the diastole and the more the chamber is filled with blood the less is the influence of auricular systole on the increase in volume.

Distinct *changes in volume* also take place in the auricle in connexion with the variations in pressure. These are, however, less marked than in the ventricles. Together with the rise in pressure in auricular systole, a rapid decrease in volume takes place (fig. 23 a) followed by a rapid increase at the beginning of auricular diastole. This soon ceases and is followed by a fall in the curve. After a few small variations in volume towards the end of ventricular systole, during protodiastole and isometric relaxation, a distinct decrease in the volume of the auricle occurs in connexion with the opening of the auriculo-ventricular valves. This corresponds to the rapid inflow. During the slow filling phase or diastasis, on the other hand, the auricle increases in volume, to be followed once more by a decrease together with auricular systole.

Mean figures for the different cardiac phases according to Wiggers

Isometric contraction	0.05 second
Maximum ejection	0.09 »
Reduced ejection	0.13 »
Total systole	0.27 second

Protodiastole	0.04	second
Isometric relaxation	0.08	»
Rapid inflow	0.11	»
Diastasis	0.19	»
Auricular systole	0.11	»
Total diastole	0.53	second

Fig. 23 a

Fig. 23 b

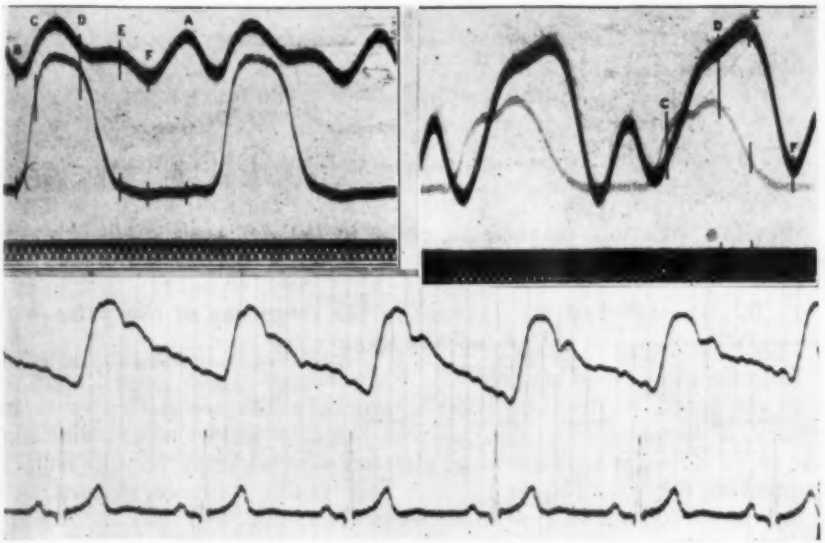


Fig. 24 b

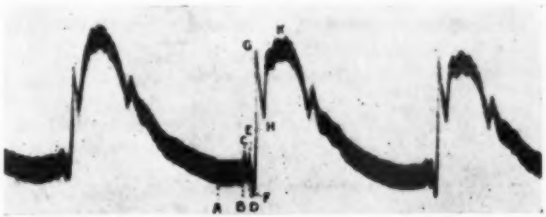


Fig. 24 a

Fig. 23. Auricular volume (dark curves) and intraventricular pressure (lighter curve). Left set, normal; right set, during mitral regurgitation (after WIGGERS).

Fig. 24. Pulmonary artery a) arterial pressure curves (after WIGGERS) b) volume curves.

F. The effect of respiration on the Ekyg

Changes in pressure in the vessels and the heart take place in connexion with the intrathoracic pressure variations occurring during respiration. Amongst other effects the time of opening of the semilunar valves varies during the different phases of respiration. This variation is most apparent in the pulmonary circulation. The pulmonary artery is namely dilated on inspiration and the pressure falls, whereas it is compressed on expiration and the pressure rises (v. fig. 24 a, b). This fluctuation in the diastolic pressure in the pulmonary artery is the cause of the variation in the opening times of the pulmonary valves. According to WIGGERS, the pressure variations in the pulmonary artery during expiration and inspiration are approximately the following:

	Expiration	Inspiration
Systolic pressure	60	32 mm Hg
Diastolic pressure	21	6 » »

Similar variations in pressure occur in the aorta although they are somewhat less marked.

G. The effect of the changes in the frequency of the pulse on the Ekyg

The first and most marked effect of changes in the pulse frequency is on the length of diastole. With a successive increase in the pulse frequency, a decrease first takes place in the slow inflow phase, diastasis. The rapid inflow is not, however, affected other than in very high pulse frequencies, *i. e.* over 150 per minute. This results, it is true, in a decrease in the pulse volume with a rising heart frequency, but only to any appreciable degree with a very high frequency. The shortening of diastasis with a rising pulse frequency is seen distinctly from the volume curve in fig. 25 a—b. A decrease in the length of systole also takes place with an increase in the pulse frequency. This is, however, considerably smaller than for diastole, as is seen from table 1 (WARBURG).

Heart frequency	Systole	Diastole
60	0.38 second	0.62 second
90	0.33 »	0.33 »
120	0.30 »	0.20 »
150	0.28 »	0.12 »

H. The relation between the E. C. G. and the action of the heart

The specific muscle tissue in the sino-auricular node comprises the pacemaker which determines the rhythm of the heart under normal

Fig. 25 a

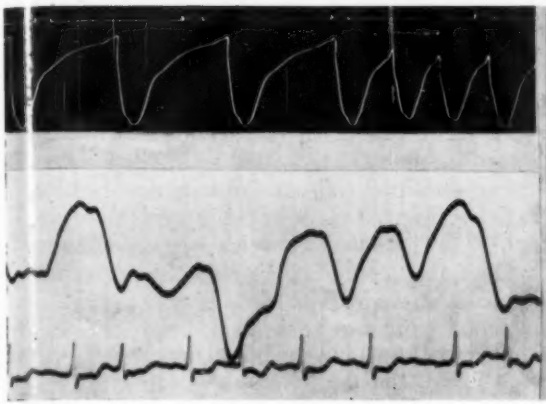


Fig. 25 b

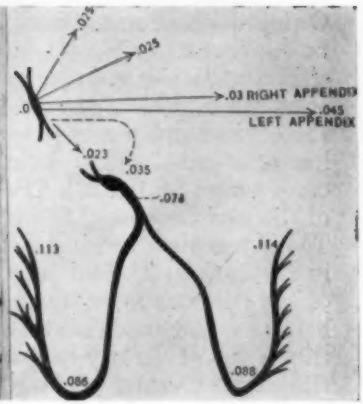


Fig. 26

Fig. 25. Volume curves showing decreased diastole, abolition of diastasis phase and reduction in systolic discharge during cardiac acceleration (after WIGGERS).

Fig. 26. Diagram showing the conduction system of the heart and approximate times of spread of the impulse over the auricular and ventricular conduction systems (after WIGGERS).

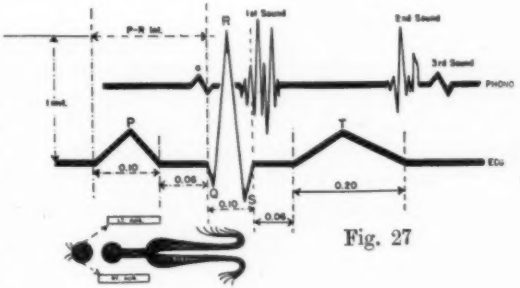


Fig. 27

Fig. 27. Duration and height of the different waves of the electrocardiogram; comparison with the sound tracing (phono) and with the transmission of the stimulus in the conducting system (after LUISADA).

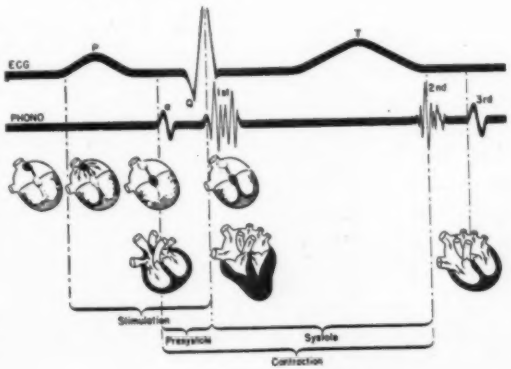


Fig. 28

Fig. 28. The different waves of the electrocardiogram and their relation to the phases of cardiac expansion and contraction (after LUISADA).

conditions. From it proceeds the stimulus to the auricle and thence through the stimuli-conveying bundle of His to the ventricles (v. fig. 26). Owing to the fibrous dividing wall, the stimulus from the auricle cannot be conveyed to the ventricles by any other path than through this specific muscle tissue. Injuries to it give therefore rise to disturbances in conduction, which can lead to a dissociation between the activity of the auricle and the ventricle. In connexion with the stimulation of the heart, so-called action currents arise, that are recorded with the electrocardiograph (v. fig. 27). The curve obtained reflects the stimulation both of the auricles and of the ventricles. Fig. 28 shows such a typical curve. The P wave occurs simultaneously with the distribution of the stimulus in the auricle, its beginning presumably corresponding to the spreading of the stimulus from the sino-auricular node. The view is now generally held that the expulsion of the blood from the auricle does not start until the end or slightly before the end of the P wave and that it lasts until the start of ventricular contraction at the level of or slightly after the R wave. The auricular contraction starts in the upper parts of the auricular wall and continues downwards towards the base, as is seen in fig. 18 b.

The QRST or ventricular complex corresponds to the spreading of the stimulus in the ventricular muscles and to ventricular systole. In this complex, QRS is considered to correspond to the distribution of the stimulus in the walls of both ventricles. In the opinion of the majority of writers, the isometric contraction of the ventricles starts between R and S, presumably in the middle of the descending limb between R and S or possibly at the level of S. It lasts for approximately 0.06 second and is followed by the phase of ejection, which is usually terminated at the end of the T wave.

I. The Material

The material on which the interpretation and description of the electrokymographic curves in the following are based comprised:

1. Normal subjects, who showed no signs or symptoms of cardiac disorders in the case-history, on clinical or physiological examination or on ordinary roentgenological examination.

2. The pathological cases, selected so that use was only made of those patients in whom the pathological changes stated were evident on clinical and physiological examination and possibly roentgenologically.

	No.		No.
Normal subjects	97	Mitral stenosis and insufficiency	23
Mitral insufficiency	15	Aortic insufficiency	11
Mitral stenosis	7		

	No.		No.
Aortic stenosis	2	Auricular fibrillation	4
Pulmonary insufficiency	2	Ventricular extrasystole	6
Aortic aneurysm	2	Complete A—V block	2
Pulmonary aneurysm	1	Intraventricular block	6
Aneurysm of the ventricular wall	2	Pre-excitation	4
Hypertension	17	Congenital heart defects	8

ELECTROKYMOGRAPHY

I. Normal subjects

1. *Left ventricle*

The photocell is placed, as shown in fig. 14, at a number of sites along both the lateral and the posterior borders. The curves obtained all have a common characteristic feature but at the same time differ somewhat from each other. If the curve from the apex (fig. 29 a—c) is

Fig. 29 a

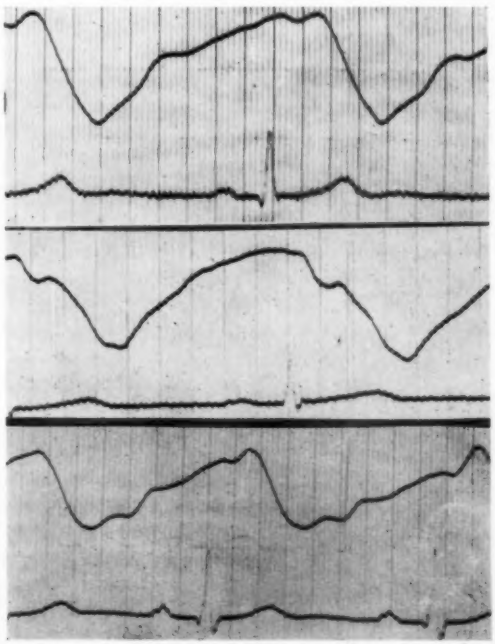


Fig. 29 b

Fig. 29 c

Fig. 29 a—c. Ekyg of the left ventricle at the apex from three different persons.

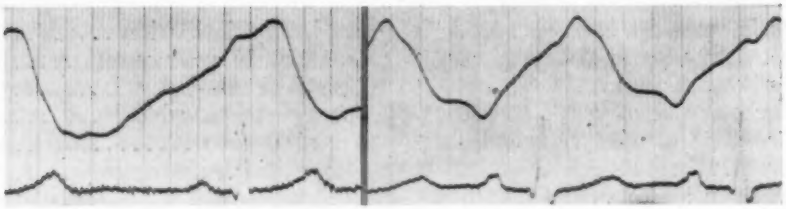


Fig. 30 a[1] Fig. 30 a[2]

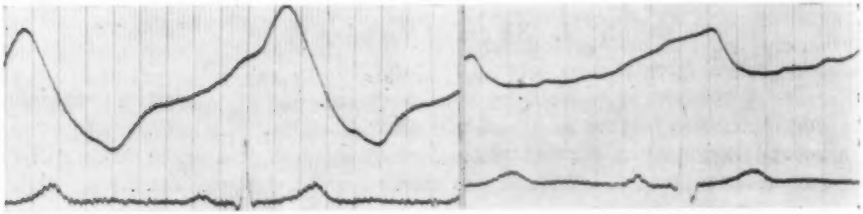


Fig. 30 b[1] Fig. 30 b[2]

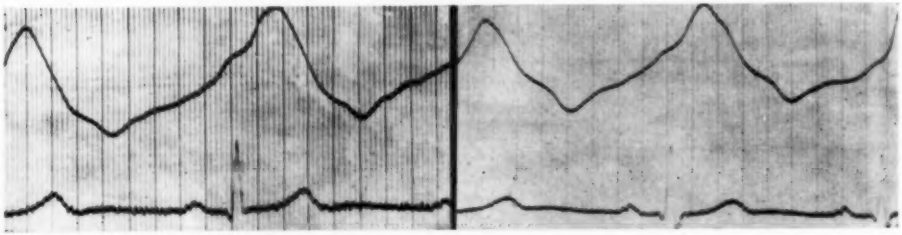


Fig 30 c Fig. 39 d

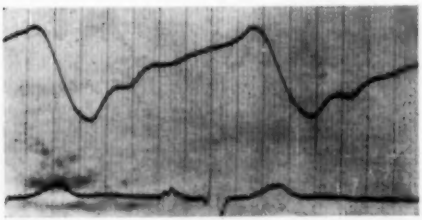


Fig. 30 e

Fig. 30 a. Ekyg from the middle part of the left ventricle.

Fig. 30 b. Ekyg from the base part of the left ventricle.

Fig. 30 c. Ekyg from the posterior wall of the left ventricle between the base and the apex.

Fig. 30 d. Ekyg from the posterior wall of the left ventricle at the base.

Fig. 30 e. Ekyg from the posterior wall of the left ventricle at the apex.

aken as the point of departure, it is seen that during the isometric contraction of the ventricles, which starts 0.07—0.08 second after the Q wave and 0.03—0.04 second after the R wave and lasts for approximately 0.06 second, the curve falls rapidly due to an inward movement of the apex. During the ejection phase, the curve first shows a further fall and is finally flattened somewhat towards the end. A small wave-shaped movement is usually seen at the transition between the isometric and the ejection phase. Shortly after the end of the T wave, when the systolic phase has ceased and continued into the protodiastolic phase, the curve turns and then rises during isometric relaxation and the rapid inflow, most rapidly during the latter phase. The total duration of protodiastole, isometric relaxation and rapid filling is approximately 0.25 second. In the measure that the ventricle is filled, the outward movement becomes slower and the curve is flattened. If the pulse frequency is very slow, no or only an inappreciable change in volume occurs towards the end of diastasis. During the filling with blood that occurs in connexion with auricular systole, the ventricle is dilated further and the curve rises. When the auricular contraction ends, the curve is rounded off and then once more falls rapidly with the next isometric contraction. It is seen from fig. 29 that the ejection phase of auricular systole starts at the end of the P wave or shortly after it. The appearance of this curve is in good agreement with those obtained with the cardiometer (v. fig. 22).

If the cell is shifted up along the left border, it is seen how the curve gradually changes (fig. 30). Its appearance is more pointed. Isometric contraction starts somewhat later, 0.01—0.02 second at the base (v. fig. 30 a). This is in good agreement with the distribution of the stimulus in the stimuli-conveying system (v. fig. 26). When isometric contraction starts at the apex, an outward movement of the base takes place. The further the cell is shifted towards the base the greater the part of the isometric contraction that appears as a direct continuation of the rising diastolic curve. An inward movement of the border at the base only takes place with the start of the ejection period.

A similar change in the curve also occurs during protodiastole and isometric dilatation. The further we approach the base, the more do protodiastole and isometric relaxation become a direct continuation of the fall in the systolic curve. The end of the systole is, however, distinctly marked by a less steep slope in the curve. An inward movement of the border of the heart thus takes place in connexion with protodiastole and isometric relaxation. The ventricular curve described applies to cases with a normal heart frequency, *i. e.* approximately 70 beats per minute. If the pulse frequency increases, the length of diastasis decreases in proportion. With a frequency of more than 100 beats per minute, the

Fig. 31 a

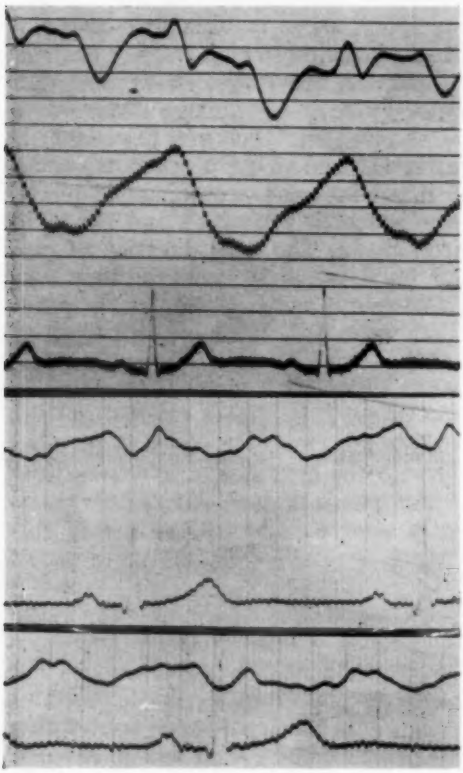


Fig. 31 b

Fig. 31 c

Fig. 31 d

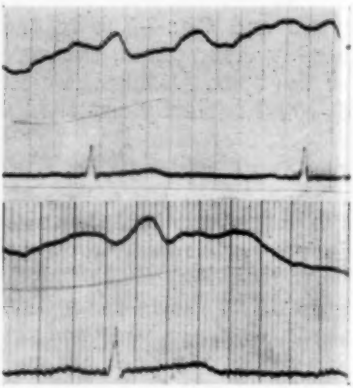


Fig. 31 e

Fig. 31. a—e. Ekyg of the left auricle.

rapid filling continues directly into auricular systole. The upward phase in the Ekyg curve has then an almost straight course until the beginning of isometric contraction.

A more or less distinctly marked inward movement of the border at the level of the end of the P wave is seen in many instances in the curves taken over the base. The movement coincides with the isometric contraction of the auricle and evidently depends on the base being drawn upwards (v. fig. 61). The fact that the ascending aorta, as seen in fig. 6[illegible], makes small outward movements during this period also supports this assumption.

2. *Left auricle*

The movement of the auricular wall is considerably less than that of the ventricles and is entirely different in appearance. Because of its thin and poorly muscularized wall, the movement of the auricle is partially affected by that of the ventricle. The patient must be turned to the right in order to record the movements of the left auricle. In the direct frontal view, only the appendage forms a border and if this is small, the curve is difficult to interpret owing to the superimposed movement of the ventricle. The more the patient is turned to the right, the larger is the part of the left posterior border of the heart formed by the auricle. The normal auricular curve (v. fig. 31 a—e) has a very characteristic appearance and reflects to a considerable extent the variations in pressure in the auricle. A fairly appreciable fall in the curve on a level with and immediately after the end of the P wave is seen in connexion with auricular systole. This fall continues until the start of isometric ventricular contraction, when it rises rapidly. This is presumably caused by the bulging inwards of the auriculo-ventricular valves. If this curve is compared with the pressure curve in fig. 20 B, it is seen that a distinct increase in pressure occurs in the auricle during this period. In connexion with the rapid ejection phase, the base of the ventricle moves downwards towards the apex drawing the auricle with it. This results in an inward movement of the auricular wall, which can be seen distinctly in fig. 31. Towards the end of ventricular systole, the auricular curve shows a more horizontal, small-waved course. At the end of isometric relaxation, however, it falls suddenly. The beginning of this fall in the curve marks the opening of the auriculo-ventricular valves. Following this considerable fall during the rapid inflow, the curve once more rises during diastasis. This indicates that the inflow to the auricle is larger than the outflow. The curve continues to rise until auricular systole occurs. The shape of the auricular curves described in the foregoing is in good agreement with that obtained cardiometrically as described by WIGGERS (cf. fig. 23 a).

3. *Right auricle*

As regards the shape of the curve, the »pulsations» of the right auricle do not differ from the left (v. fig. 32 a—e). On the other hand, the time relations are often somewhat dissimilar. Thus, we found that the auricular contraction on the right side frequently started about 0.01 second earlier than the left. Moreover, the auriculo-ventricular valves on the right side usually open somewhat earlier than on the left, in many instances up to 0.04 second earlier. The latter is presumably associated with the fact that the right ventricular wall relaxes more quickly than

Fig. 32 a

Fig. 33 c

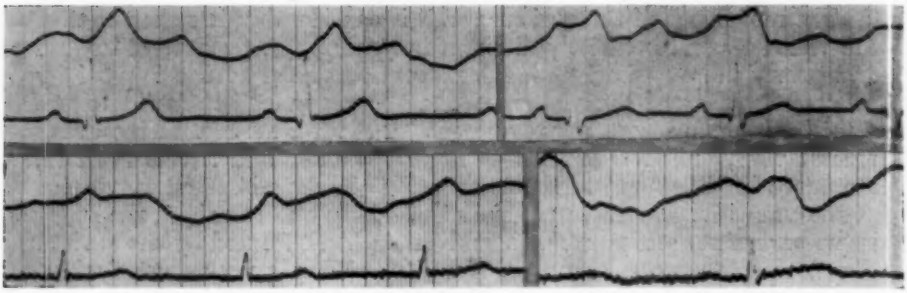


Fig. 32 b

Fig. 32 d

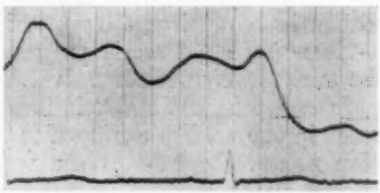


Fig. 32 e

Fig. 32. a—e. Ekyg of the right auricle.

the left. In the examination of the right ventricle, we have found it to be of great importance to take an Ekyg as a matter of routine in the direct frontal position or possibly with the patient slightly turned to the right. Right ventricular enlargement takes place to the right and displaces the right auricle. Typical ventricular contractions are then found at the site of the auricle. In addition to the forementioned curves, an Ekyg of the posterior outline of the auricle with the patient turned to the left is also taken as a matter of routine.

4. *Right ventricle*

Because of the position of the ventricle close to the anterior thoracic wall this cannot be studied as thoroughly as the left. The only possibility of obtaining an outline of the ventricle is to turn the patient considerably to the right (fig. 33) or in individual cases to the left as well (fig. 34). Parts of the anterior surface are then visible. The curves obtained in the first instance have the same appearance as in the upper part of the left ventricle, whereas in the latter they are reminiscent of the curves for the ventricular apex. The time relation between the right and left ventricles varies somewhat and an asynchronism is often present, since in the majority of cases contraction begins somewhat earlier in one ven-

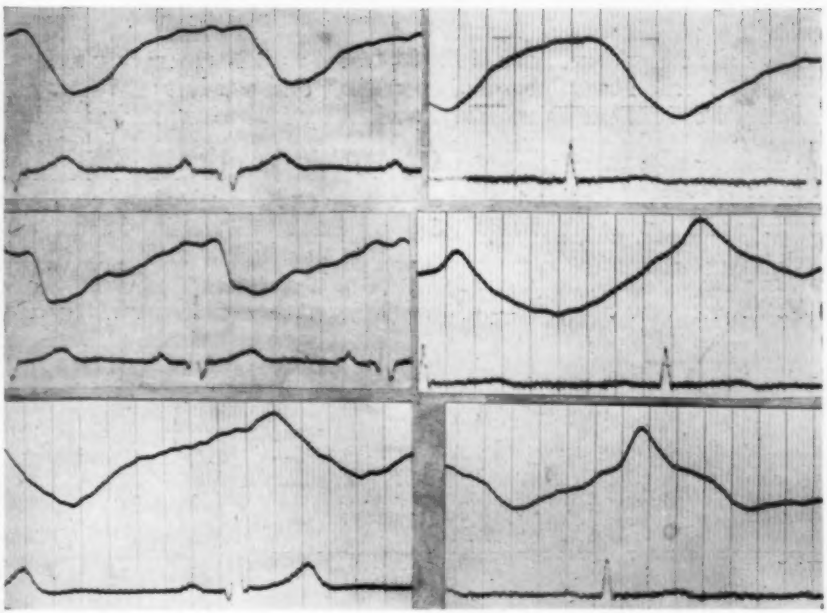


Fig. 33 a²

Fig. 33 b²

Fig. 33 c²

Fig. 33. Ekyg of the right ventricle turned to the right. a) at the apex, b) in the middle, c) at the base.

tricle than in the other. Less frequently does the contraction occur simultaneously on both sides. We have found that this asynchronism can amount to 0.03 second but does not usually exceed 0.01—0.02 second. In our material the left ventricle appears to take the lead approximately as often as the right. That an asynchronism between the two ventricles can exist was observed earlier by KATZ (1925) in experiments on dogs. This has later been verified by ELLINGER et al. (1947) in man. In time studies of both ventricles, it must nevertheless be borne in mind that corresponding parts must be compared and that the apex of the left ventricle cannot be compared with the base of the right.

5. *The pulmonary artery*

It is necessary on recording to turn the patient fairly far to the left, partly because of the position of the main stem and partly on account of the influence that the left pulmonary branch can exert on the cell. Greater accuracy in time registration is thereby obtained since the photocell can be placed in fairly close connexion to the semilunar valves.

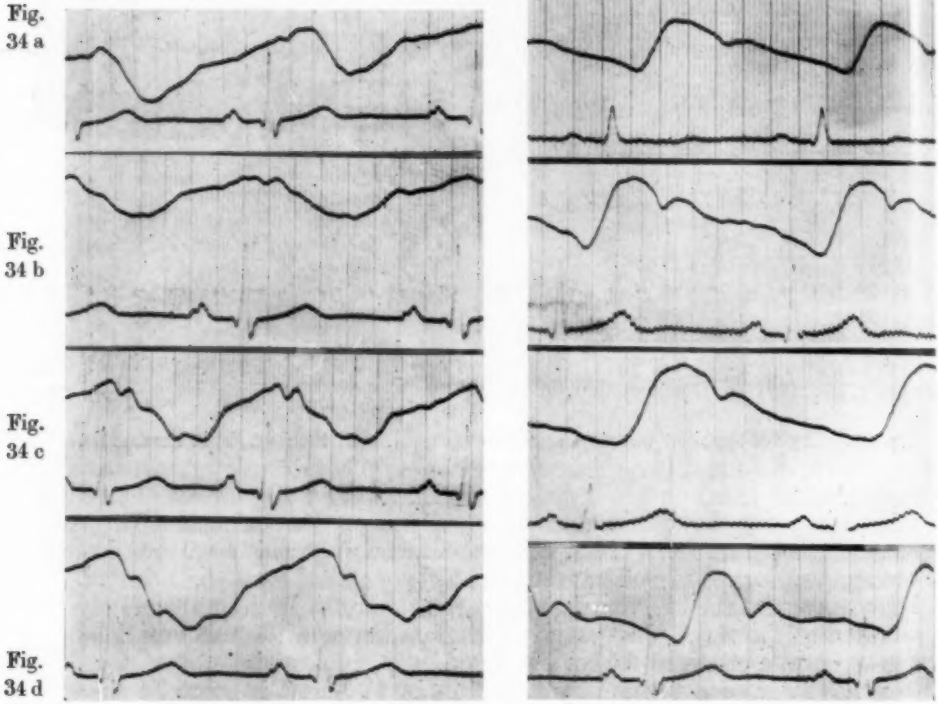


Fig. 34. Ekyg of the right ventricle turned to the left. a) at the apex, b—c in the middle, d) at the base.

Fig. 35. Ekyg of the pulmonary artery.

The more the photocell is shifted peripherally, the greater is the time displacement in the pulse curve. The Ekyg of the pulmonary artery has a very typical appearance and is reminiscent of the pressure curves obtained for this vessel (v. fig. 35 a—e). In connexion with or shortly after the opening of the semilunar valves — depending on how near to the valves the photocell is placed — an abrupt rise occurs in the curve.

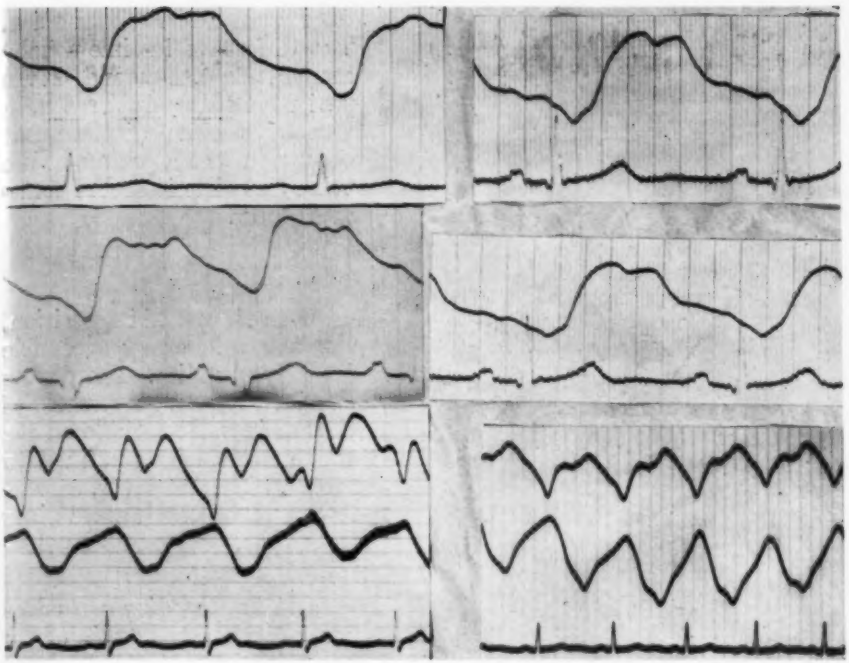


Fig. 36. Ekyg of the ascending aorta.

This continues during the entire rapid outflow phase. During the slow ejection phase towards the end of systole, the pressure falls. The curve is then flattened and begins slowly to fall. A rapid and fairly sudden fall in the curve takes place at the end of the T wave in connexion with the closure of the semilunar valves. This is interrupted by a dilatation of the vessel in connexion with the reflux of blood. The curve falls slowly during the whole of diastole and is flattened somewhat shortly before the next systole. A small wave-shaped movement on the curve is often visible in connexion with the isometric contraction of the ventricles. The transition between the rapid and slow outflow phase can be more or less marked. In young subjects with a normal circulation the transition is usually well defined. The time for the opening of the semilunar valves varies from one individual to another but is usually 0.08—0.1 second after the peak of the R wave. It is fairly markedly influenced by the respiratory phase (v. fig. 24). During inspiration, when both the systolic and the diastolic pressure in the pulmonary artery fall, the valves open

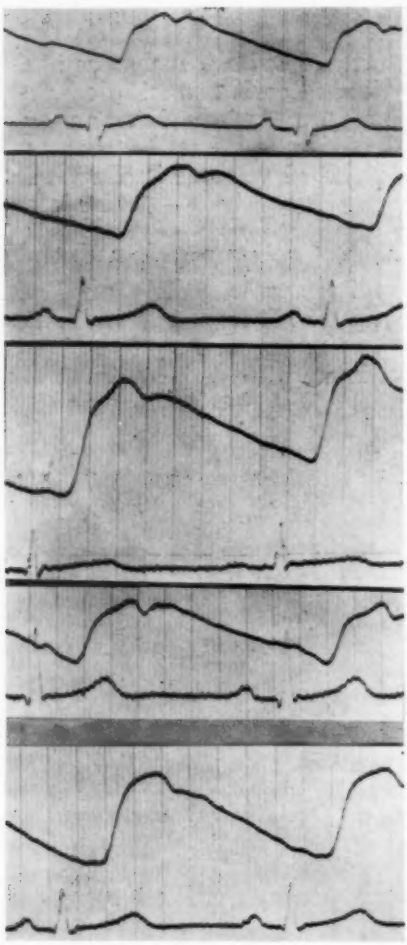


Fig. 37. Ekyg of the aortic knob.
Fig. 38. Ekyg of the descending aorta.

earlier than during expiration. The difference in time usually amounts to 0.02 second. If the patient holds his breath, a successive time displacement occurs in the opening of the valves so that it occurs somewhat later.

6. *Aorta*

On account of its position, the aorta is easily accessible for Ekyg studies. The curves obtained for the movements of the aortic wall resemble on the whole those of the pulmonary artery. Since, however, the different parts of the aorta differ somewhat, they must be treated separately.

a. *The ascending aorta* does not, as mentioned earlier, form a border in the frontal plane. In order to study this part, the patient must therefore be turned fairly far to the right. If the turning is not satisfactory the pulsations from the large veins are superimposed to a greater or lesser extent. In order to obviate large displacements in time, the photocell should be placed as far down as possible, although not so low that it is influenced by the right ventricle or right auricle. The transition between the ascending aorta and the right ventricle or right auricle is usually distinctly marked and is easily visible on screening. The curve obtained for this section is altogether typical and differs partially from those obtained from the pulmonary artery and the other parts of the aorta (Fig. 36 a—f). It is often more flattened and not infrequently has

Fig. 39 a Fig. 40

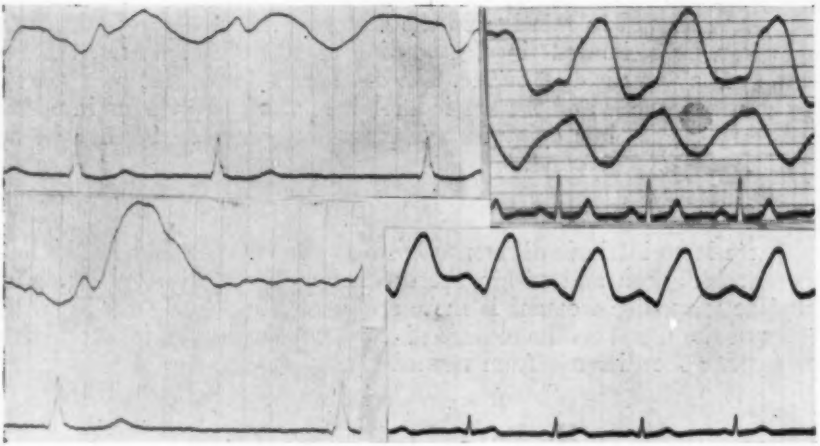


Fig. 39 b Fig. 39 c

Fig. 39. Ekyg of the left auricle in mitral insufficiency.
Fig. 40. Ekyg of the left auricle in severe mitral insufficiency.

a double-humped appearance (e—f). The peak found in connexion with the reflux is sometimes higher than that during systole. A slight rise in the curve occurs at times in connexion with the isometric contraction of the ventricles. The opening of the semilunar valves is, however, marked by a very steep rise. This opening usually takes place 0.08—0.1 second after the R wave but small time deviations in one or the other direction can occur in normal individuals. Respiration also plays a certain rôle in the curve of the aorta although less than for that of the pulmonary artery.

b. *The aortic arch*

The curves recorded for the aortic knob are very reminiscent of those for the pulmonary artery (fig. 37 a—d). The transition between the rapid and slow ejection phases is, however, usually more distinct and the curve is often more flattened in the first part of the slow outflow. The contraction of the vessel during diastole is often slower than in the case of the pulmonary artery, resulting in a straighter course in this part of the curve. The curve then falls continuously until the semilunar valves once more open. A time displacement, depending on the length of the aorta and its elasticity, the rate of the pulse wave and the position of

the photocell, takes place in the aortic curve. If the photocell is placed in the middle of the aortic knob, the delay in normal cases is usually 0.01—0.02 second in relation to the curve of the ascending aorta. The delay can be estimated since, according to REIN, and others, the rate of the pulse wave is 4—5 m/sec. The distance between the lower part of the ascending aorta and the aortic knob is approximately 8 cm in normal individuals. The time delay in this part of the curve will then be approximately 0.015 second.

c. *The descending aorta*

There is no intrinsic difference between the curves taken at the level of the aortic arch and within the descending aorta with the exception that the time displacement is more apparent (fig. 38). In addition, the reflux of the blood on the closure of the semilunar valves is less distinct the further the distance from the ascending aorta.

II. Pathological cases

A. Acquired diseases

1. *Mitral insufficiency.* It is typical of mitral insufficiency that, during systole, the blood is regurgitated into the left auricle owing to patency of the mitral valve. The volume of the reflux depends on the extent of the defect. The filling conditions of the auricle are thereby altered and are distinctly visible on the Ekyg curves (fig. 39 a—c). As mentioned earlier, an inward movement of the auricular wall takes place in normal subjects in connexion with the downward movement of the base of the ventricle during ventricular systole. This causes a definite fall in the curve, whose duration is usually 0.08—0.1 second. This fall is followed by a more horizontal partly wavy course until the opening of the auriculo-ventricular valves. Its horizontal part lies partly below or approximately on a level with the peak obtained during isometric contraction. In mitral insufficiency, on the other hand, it is interrupted at an earlier stage by the downward movement of the curve caused by the movement of the base. The time for the interruption is entirely dependent on the amount of the leakage. The curve then rises more or less sharply until the end of the systole at the level of the end of the T wave. Presumably on the grounds of the increased pressure in the auricle and the pulmonary circulation, the diastolic flow to the ventricle begins earlier and the curve falls almost immediately after the peak is reached. These changes are more or less marked according to the degree of the lesion. If the leakage between the auricle and ventricle is considerable, no fall in the curve is marked in connexion with the basal movemen

Fig. 41 a

Fig. 42

Fig. 44 a

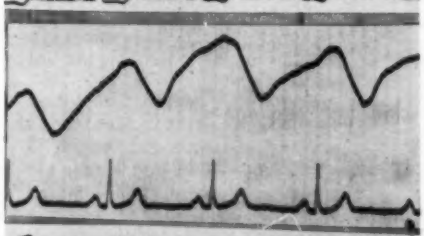


Fig. 44 b

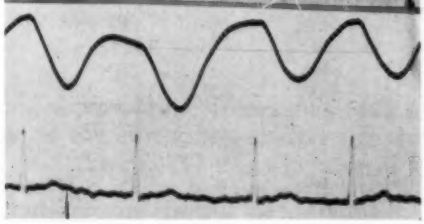


Fig. 41 b

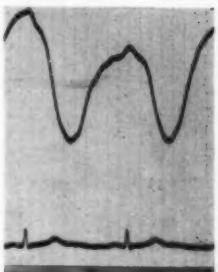


Fig. 43

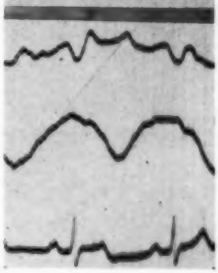


Fig. 41. Ekyg of the left ventricle in mitral insufficiency.
Fig. 42. Ekyg of the enlarged right ventricle in mitral insufficiency.
Fig. 43. Ekyg of the left auricle in mitral stenosis.
Fig. 44. Ekyg of the left ventricle in mitral stenosis.

but it rises continuously from the beinning of the isometric contraction and to the end of systole (fig. 40). This finding is in good agreement with those of WIGGERS in his cardiographic studies of experimentally produced mitral disorders (v. fig. 23 b).

With this type of lesion no great time displacement appears in the ventricular curve. In the more severe cases, however, the rapid inflow begins earlier than normally (fig. 41 a—b). It is also seen that the transition between isometric contraction and the rapid ejection phase is less distinct. Some straightening of the curve also takes place during protodiastole and isometric relaxation.

Particularly in more severe mitral lesions, a delayed opening of the pulmonary valves is observed owing to the increased pressure in the pulmonary artery. This delay can amount to 0.03—0.04 second. In con-

Fig. 45 a

Fig. 45 b

Fig. 45 c

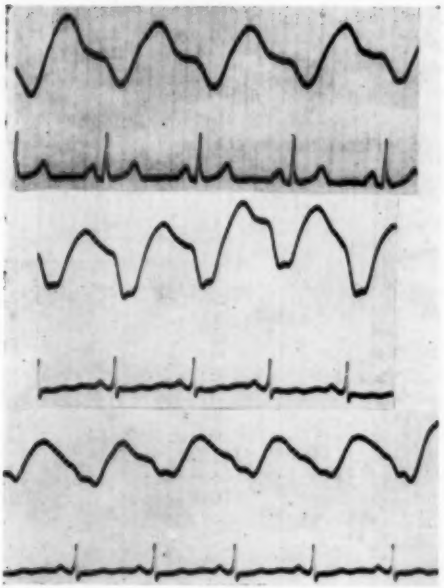


Fig. 46 a

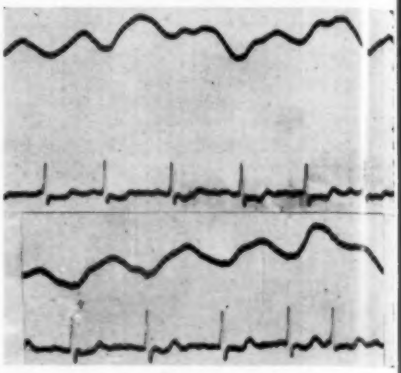


Fig. 46 b

Fig. 45. Ekyg of the left auricle in combined mitral insufficiency and stenosis.

Fig. 46. Ekyg of the left auricle in combined mitral insufficiency et stenosis with high pulse rates.

nexion with it an enlargement of the right ventricle appears, evidenced by the presence of typical ventricular pulsations at the site at which auricular pulsations are recorded in normal cases (v. fig. 42).

2. *Mitral stenosis.* In contradistinction to mitral insufficiency, no change in the auricular curve is found during ventricular systole but first during diastole (figs. 43 and 45 a—b). In normal cases a fairly rapid inward movement of the auricular wall takes place during the rapid inflow. This continues into an outward movement with diastasis. In stenoses, the emptying of the auricle takes place more slowly, resulting in a slowing of the inward movement and a less steep fall in the curve. In severe stenosis practically no difference is visible in the movement during the rapid inflow and diastasis but the auricle empties continuously. This causes the curve to fall fairly evenly from the start of the rapid inflow until the end of ventricular systole. Because of the hypertrophy of the auricular muscles, the auricular systole is strong and is evidenced on the curve by a considerable fall. The auricular systole is also presumably somewhat lengthened, since the normal outward movement of the auricular wall in isometric contraction is not infrequently observed 0.01—0.02 second later than is normal. At times the inward movement dur-

Fig. 47 a

Fig. 47 b

Fip. 47 c

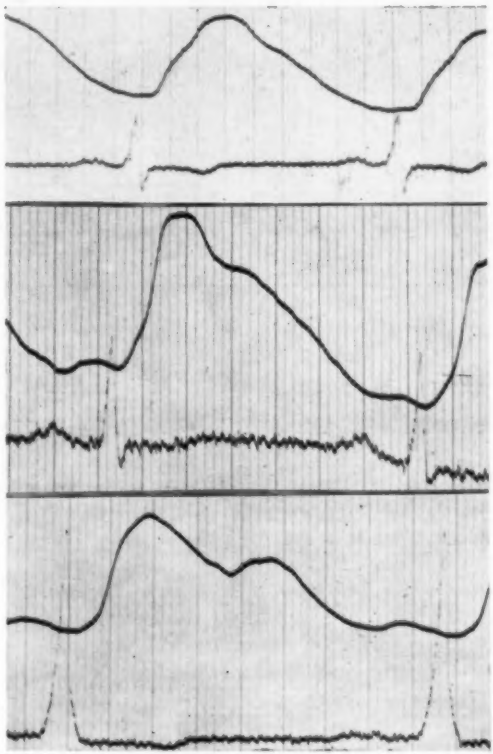


Fig. 47. Ekyg of the ascending aorta in aortic insufficiency.

ing the rapid inflow is seen to be interrupted earlier than is normal and to continue into an outward movement.

The ventricular curve is also altered in appearance with mitral stenosis (v. fig. 44 a—b). A marked difference between the rapid inflow and diastasis is seldom visible and the rise in the curve is somewhat less steep from the start. A considerable filling of the ventricle occurs with ventricular systole, evidenced by a steep rise in the curve (v. fig. 44 a). Because of the increased pressure in the pulmonary circulation, the opening of the pulmonary valves is delayed.

Although simple mitral stenosis is not uncommon, it nevertheless most commonly occurs in combination with mitral insufficiency. The Ekyg curves then have an appearance characteristic of both types of lesion, with a change in the ventricular curve in both the systolic and

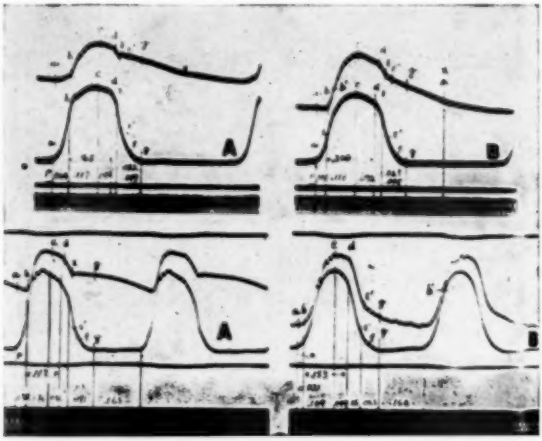


Fig. 48. Two sets of pressure pulses showing effects of mild and severe aortic regurgitation on pressure pulses of the aorta (upper) and left ventricle (lower). Left side curves (A), normal controls; right side curves (B), effects of experimental lesions. Time 0.02 sec. (after WIGGERS).

the diastolic phases (fig. 45 a—c). If the pulse frequency is high, the diagnosis of mitral stenosis is rendered more difficult on the grounds of the considerable shortening of diastole. The auricular systole then appears as a direct continuation of the rapid inflow, whereas diastasis disappears either altogether or to a considerable extent (fig. 46 a—b). In these cases as well, auricular systole is strongly marked on the ventricular curve owing to the fact that the ventricle is filled to a lesser degree than is normal.

3. *Aortic insufficiency.* Aortic insufficiency is among the lesions that are easiest to assess with the Ekyg (fig. 47 a—c). As mentioned earlier, in normal cases no blood is expelled into the aorta until after the end of isometric contraction, approximately 0.09 second after the peak of the R wave. This is due to the fact that the ventricular pressure does not exceed the diastolic pressure in the aorta before this time. In aortic insufficiency, the diastolic pressure in the aorta falls lower than is normal owing to the leakage, and the ventricle therefore overcomes this pressure at an early stage. The greater the leakage, the lower is the diastolic pressure and the earlier is the blood forced out into the aorta.

It is clearly visible on the Ekyg how the aorta begins to dilate even during isometric contraction. The more severe the lesion, the earlier does this occur. In severe aortic insufficiency with a diastolic pressure approaching zero, the aorta dilates almost immediately isometric contrac-

Fig. 49

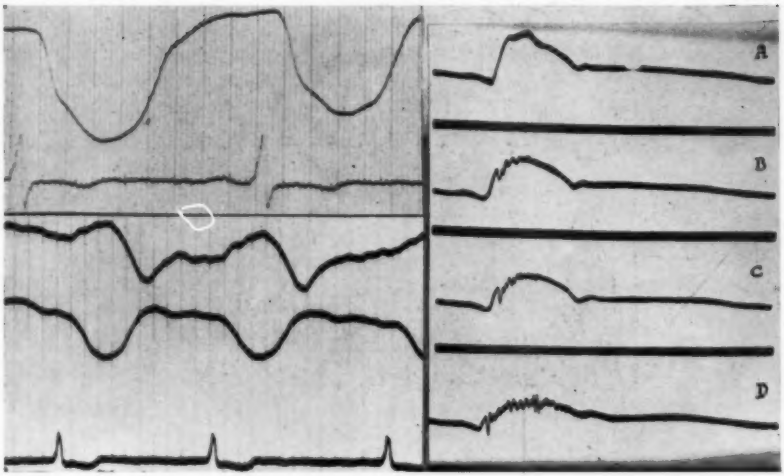


Fig. 50 Fig. 51

Fig. 49. Ekyg of the left ventricle in aortic insufficiency.
Fig. 50. Ekyg of the ascending aorta in aortic stenosis (upper curves).
Fig. 51. Four aortic pressure pulses from the dog showing changes in contour and amplitude with increasing degrees of aortic stenosis (after WIGGERS).

tion starts. It is also typical of aortic insufficiency that the recoil of the blood column during the period of reflux is diminished because the aortic valves do not close entirely, or in severe lesion, there is no closure at all. Because of the leakage, the pressure in the aorta falls more rapidly and causes the aortic wall to contract earlier. The curve therefore falls considerably more sharply during diastole and, when the lesion is severe, reaches its minimum before the beginning of the next systole. Since the blood is forced into the aorta during isometric contraction, the curve rises somewhat less sharply than in normal cases and also has a more rounded shape at the start. The latter occurrence depends on the fact that the pressure rises less rapidly in the beginning. The conditions described in the foregoing are in good agreement with the results obtained experimentally by WIGGERS (v. fig. 48).

In aortic insufficiency the ventricular curve also undergoes a distinct change (v. fig. 49). The transition between isometric contraction and the rapid ejection phase becomes less marked or disappears entirely. It is not uncommon for the rapid inflow to start earlier because of the back-pressure of the blood from the aorta and the curve often rises more steeply

Fig. 52 a

Fig. 52 c

Fig. 54

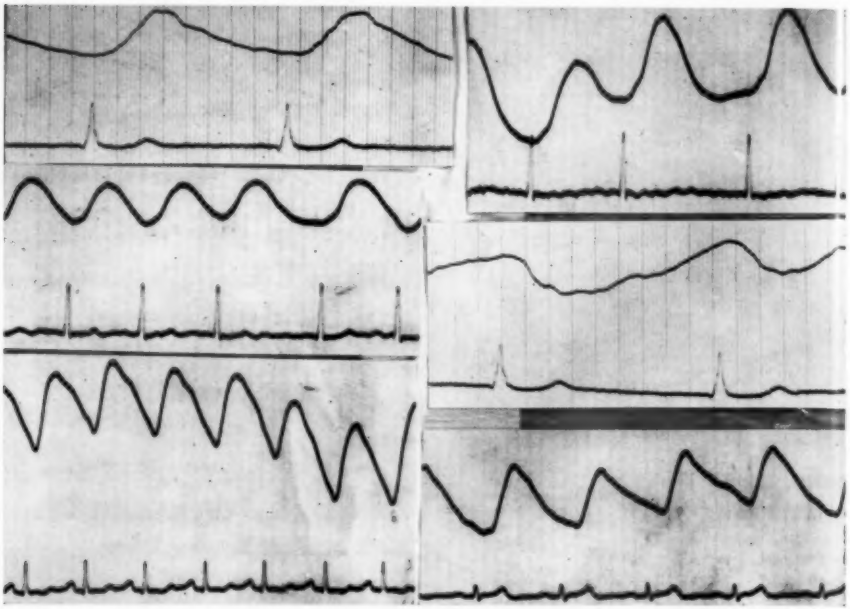


Fig. 52. a—c. Ekyg of the pulmonary artery in pulmonary insufficiency.
d. » » » right ventricle in » »
Fig. 53. Ekyg of the aortic knob distal of an aneurysm in the ascending aorta.
Fig. 54. Ekyg of the pulmonary artery distal of an aneurysm in the left branch.

during this period. In addition, auricular systole is less distinctly marked on the ventricular curve. The latter change is in proportion to the degree of the lesion.

Slight aortic lesions are among those that are most difficult to assess roentgenologically. An enlargement of the left ventricle is visible as a relatively early sign. Such an enlargement can, however, arise on many other grounds. The dilatation of the aorta described in the literature is often absent in slight cases and in the early stage of the disease. Moreover, a dilatation of the aorta can often be missed on the roentgenogram when this has not been exposed at the right cardiac phase. If the exposure is made during diastole — and this is the most usual owing to its greater duration — the aorta often appears even smaller than is normal owing to the low diastolic pressure. The pulsations typical of aortic insufficiency that are stressed in the literature are often difficult to judge on screening. The diagnosis is nevertheless considerably facilitated with the help of an Ekyg.

4. *Aortic stenosis.* The curves in aortic stenosis are considerably more difficult to judge than in aortic insufficiency. Since such purely valvular defects are rare, our material is too small to permit any definite conclusions. It appears, however, from the curves recorded that there is a somewhat less steep rise during systole than in normal subjects (v. fig. 50). In addition, there is no distinctly marked transition between the rapid and the slow ejection phases. The curve thus has a more rounded elevation. The amplitude of the pulse is diminished. These observations are to some extent in agreement with those obtained experimentally by WIGGERS, as can be seen from fig. 51.

5. *Pulmonary insufficiency.* This lesion appears only extremely rarely alone, but occurs occasionally secondarily to severe mitral lesions. For obvious reasons, the picture does not differ to any great extent from that found in aortic insufficiency (fig. 52 a—c). Thus, the pulmonary artery dilates during isometric contraction, the curve has a more rounded elevation in the beginning and rises less steeply than in normal subjects. The reflux of the blood is more or less obliterated and the curve falls more rapidly during diastole.

B. Aneurysm

1. *Aortic aneurysm.* Partly due to the changes in the elasticity of the wall and partly owing to dilatation, a more or less pronounced obliteration takes place in the details of the aortic curve (fig. 53). Its appearance is more rounded and the reflux of blood is poorly marked or not at all. This is particularly noticeable on the curve taken distal to the aneurysm, where a delayed pulse curve can also be seen at times.

2. *Pulmonary aneurysm.* The shape of the curve is on the whole similar to that obtained with aortic aneurysm (v. fig. 54).

3. *Aneurysm of the ventricular wall.* An infarct or severe myocarditis can at times cause such damage to a greater or lesser area of the ventricular wall that it loses both its contractility and its power to withstand the increasing systolic pressure. The result is a paradoxical movement of the segment of the wall involved. If an Ekyg is taken in such an area, it can distinctly be seen on the curves how the wall bulges outwards during isometric contraction and rapid ejection (fig. 55 a—b). An opposite movement occurs at the end of systole and during diastole and the curve therefore assumes an inverted appearance. Similar observations have earlier been reported by CHAMBERLAIN (1947).

Fig. 55 a

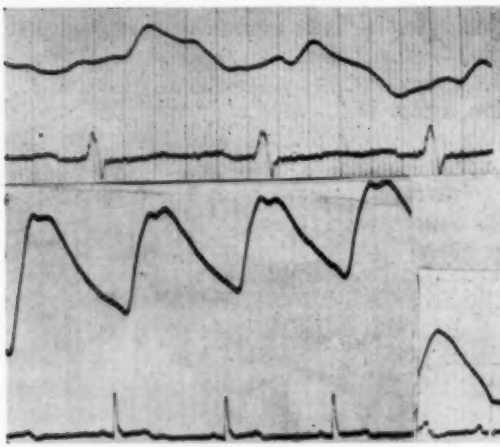


Fig. 55 b

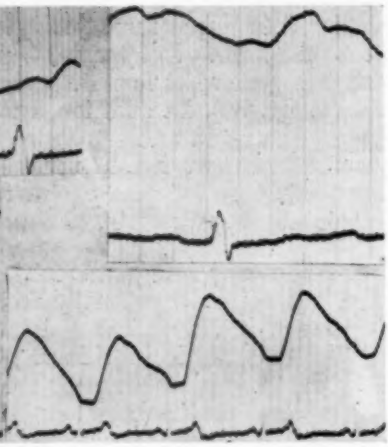


Fig 56 a

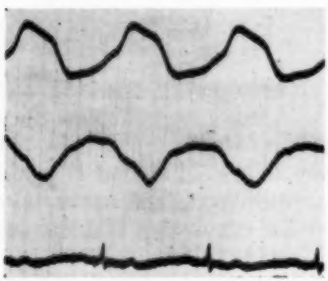


Fig. 56 b

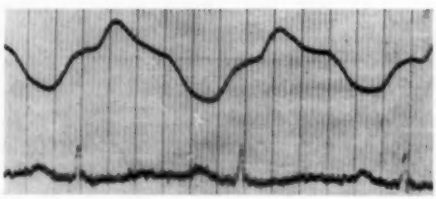


Fig. 57 a

Fig. 57 b

Fig. 55. Ekyg of an aneurysm in the wall of the left ventricle.
Fig. 56 and 57. Ekyg of the ascending aorta in hypertension.

C. Hypertension

The changes that appear on the Ekyg in hypertension are not altogether uniform and vary somewhat in individual cases. The main feature is, however, an earlier opening of the aortic valves than in normal subjects and a certain relation between the delay in the opening and the degree of hypertension (fig. 56 a—b). This is presumably associated with the fact that the higher the diastolic pressure in the aorta, the later do

Fig. 58

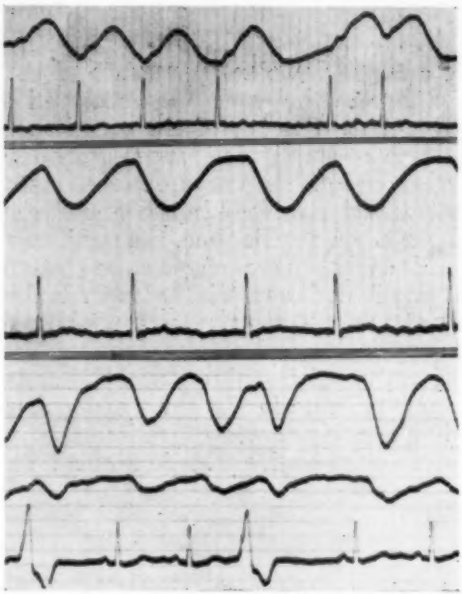


Fig. 59

Fig. 60

Fig. 58. Ekyg of the left auricle in auricular fibrillation (mitral insufficiency).
Fig. 59. Ekyg of the left ventricle in auricular fibrillation.
Fig. 60. Ekyg of the left ventricle in ventricular extrasystole.

the valves open and the later is the aorta dilated. In a number of cases we have observed at the same time a later opening of the pulmonary valves. It is not possible as yet to determine with certainty the significance of this finding but it is probable that the pressure in the pulmonary circulation is also raised. If the aorta is dilated and elongated, a fairly considerable rise in the curve is seen in the ascending aorta from the P wave and until the opening of the semilunar valves (fig. 57 a—b).

D. Arrhythmia

1. *Auricular fibrillation.* The most marked feature of this lesion is the lack of any true auricular contraction and thus no contractions can be observed on the auricular curve (fig. 58). Contrary to the normal conditions, the curve continues to rise fairly continuously during the terminal period of diastole from the end of the rapid inflow and to the beginning of the downward movement of the base of the ventricle. Nor

is there the marked increase in the ventricular volume usually observed in connexion with auricular systole (fig. 59).

2. *Ventricular extrasystoles.* The appearance of the Ekyg is entirely dependent on the time in the cardiac cycle at which the extrasystole occurs and on the phase of filling of the ventricle. If the contraction starts early in diastole its amplitude is appreciably diminished, isometric contraction is prolonged and the curve becomes more peaked (fig. 60). Owing to the small amount of blood in the ventricle and the raised diastolic pressure in the aorta at this time, the semilunar valves open considerably later. This delay can amount to more than 0.06 second. In addition, the aortic amplitude is appreciably lower. If the contraction takes place immediately after the T wave, no inflow of blood to the aorta can be observed. During the subsequent compensatory pause an abnormally powerful filling of the ventricles takes place. This, and presumably also a fall in the diastolic pressure in the aorta and pulmonary artery after the extra beat, gives rise to a shortening of isometric contraction so that the semilunar valves open earlier than is normal. The time delay can amount to 0.03—0.04 second.

E. Disorders of Conduction

1. *Complete A—V block.* In patients with a complete A—V block, the auricle and ventricle contract entirely independently. The Ekyg curves registered in the auricle and ventricle therefore vary considerably in appearance, depending on the stage in the heart phase at which auricular contraction occurs (v. fig. 61 a—k). If auricular systole takes place during ventricular systole, a contraction of the ventricle occurs despite the fact that the auriculo-ventricular valves are closed (v. fig. 61 d). Presumably, the blood is then forced back into the veins. If, on the other hand, contraction takes place during the rapid inflow, the filling of the ventricle is more rapid than is normal and is evidenced by the more rapid rise in the curve. Both the auricular and ventricular curves acquire a somewhat varying appearance, as is shown by fig. 61 a—d, according to the time at which auricular systole occurs during ventricular systole.

These curves are of great interest since they afford the opportunity of studying the different chambers of the heart separately and their mutual influence on the movements of the outlines. The description of the movement of the auricular outline given in the present paper is supported both by the forementioned and by WIGGERS' cardiometeric experiments. These curves differ very greatly from the majority of those published by ANDERSSON.

2. *Intraventricular block.* It is characteristic of this heart defect that a lesion of the impulse-conducting system has arisen on the basis of a

Fig. 61 a¹

Fig. 61 a²

Fig. 61 b¹

Fig. 61 b²

Fig. 61 c¹

Fig. 61 c²

Fig. 61 c³

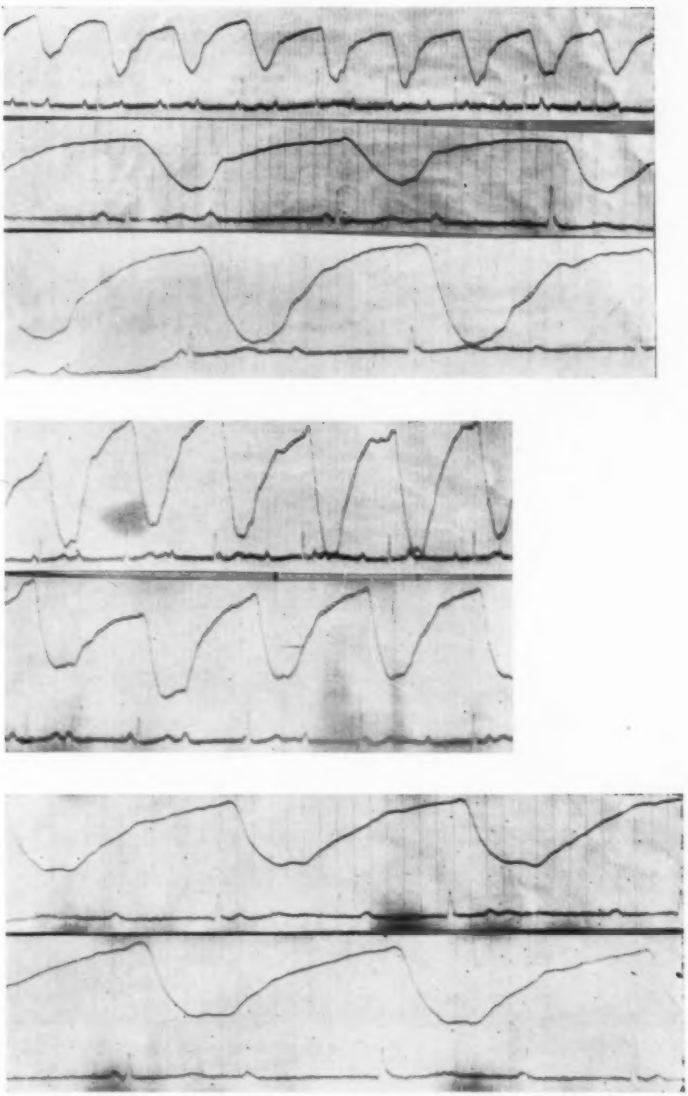


Fig. 61. Total bundle branch block.
a) apex of left ventricle. b) left ventricle (middle). c) left ventricle (base).

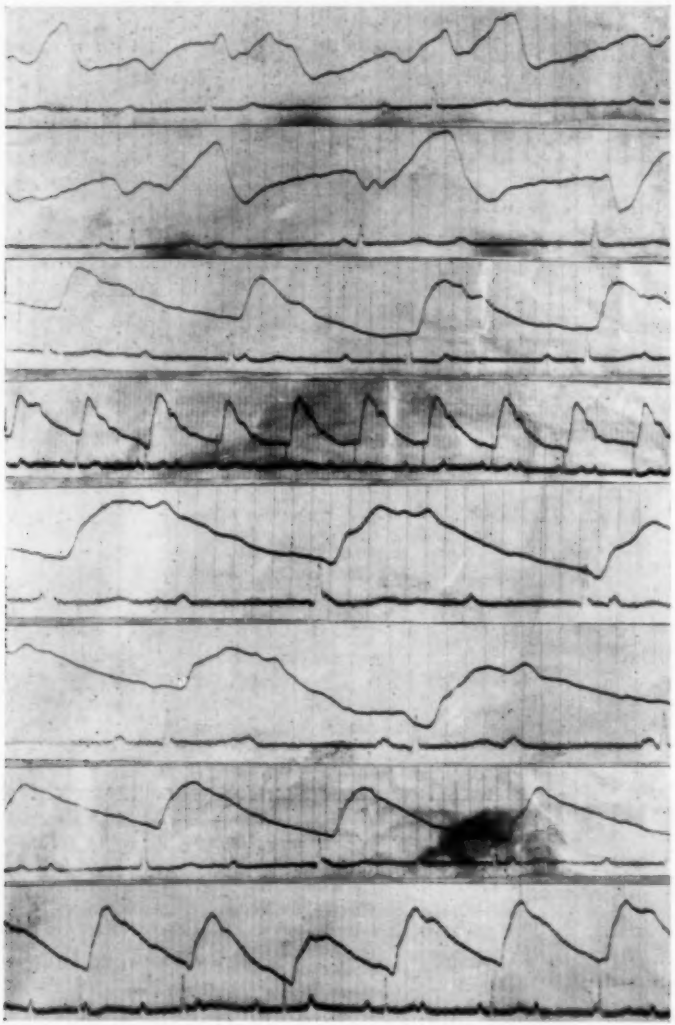


Fig. 61 d^1

Fig. 61 d^2

Fig. 61 e^1

Fig. 61 e^2

Fig. 61 f^1

Fig. 61 f^2

Fig. 61 g^1

Fig. 61 g^2

Fig. 61 (cont.). Total bundle branch block.

d) left auricle
e) pulmonary artery.
f) ascending aorta.
g) aortic knob.

Fig. 61 h¹

Fig. 61 h²

Fig. 61 i¹

Fig. 61 i²

Fig. 61 i³

Fig. 61 k

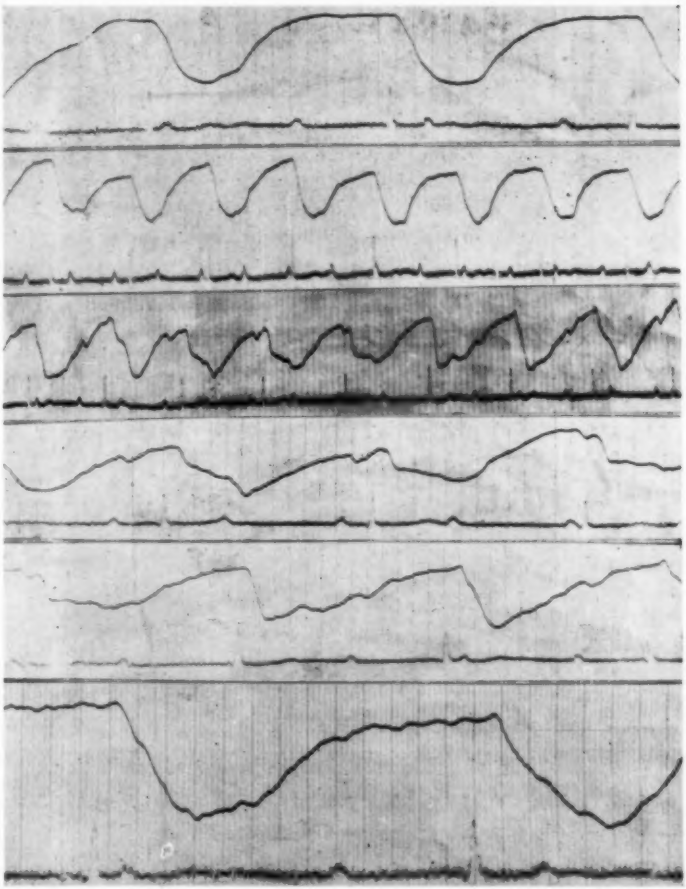


Fig. 61 (cont.). Total bundle branch block.

h) right ventricle (apex). k) right ventricle (base).
i) » » (between apex and base).

infarct or other injury. This is accompanied by a disturbance in conduction to one or other of the ventricles or to both. The changes that arise in the Ekyg are therefore to be sought in the time delay in the contraction of one of the ventricles (fig. 62 a—d). As mentioned earlier, an asynchronism is present in the majority of cases between the contraction of the ventricles, one starting to contract 0.01—0.03 second before the

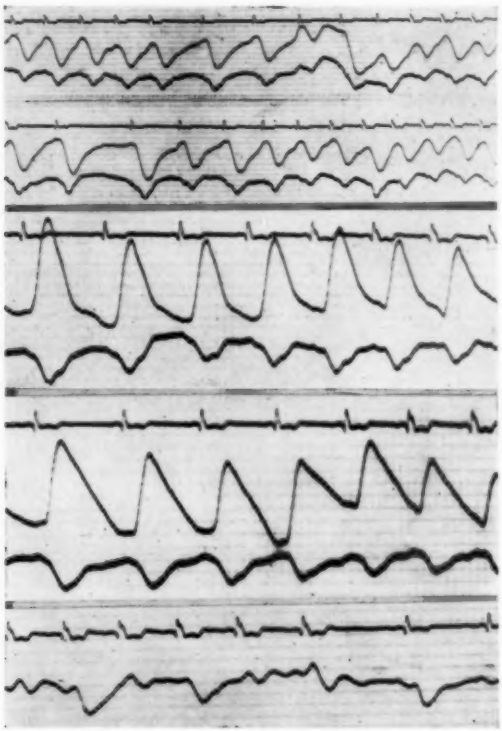


Fig. 62 a

Fig. 62 b

Fig. 62 c

Fig. 62 d

Fig. 62. Intraventricular disorder of conduction.
a) left ventricle. b) pulmonary artery. c) aorta. d) right ventricle.

other. Simultaneous contraction takes place more infrequently. With an intraventricular disorder of conduction, there is a delay in the contraction of one of the ventricles and a more pronounced asynchronism results. This is most easily seen on the curves from the aorta and the pulmonary artery. In one or two of our cases with intraventricular disorders of conduction, however, the time interval between the contraction of both ventricles was less than 0.03 second. It did not amount to more than 0.01—0.02 second. In these cases the left ventricle nevertheless took the lead and the E. C. G. curves showed a typical right-sided disorder of conduction. The explanation is presumably that, before the occurrence of this disorder, the right ventricle led by a possible 0.03 second. A delay of more than 0.06 second in the contraction of the right

Fig. 63 a

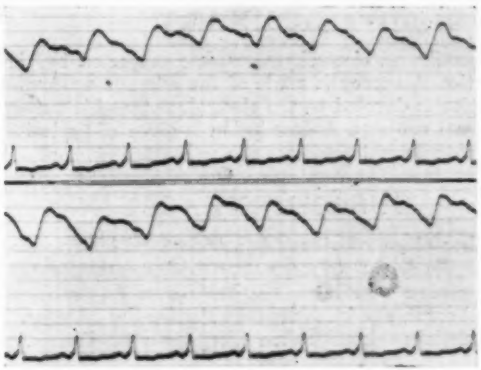


Fig. 63 b

Fig. 63. Pre-excitation.
a) pulmonary artery. b) aorta.

ventricle is then required for the values recorded to fall outside the normal variations. Such a considerable delay is nevertheless rare, as is borne out by the investigations made by ELLINGER et al. In one of two or our cases there was presumably an injury not only to one but to both branches of the impulse-conducting system. This was evidenced in the ventricular systole starting later than the normal on both sides, but considerably later on one (v. fig. 62 c—d).

3. *Pre-excitation.* No definite deviations from the normal Ekyg could be observed in any of the uncomplicated cases of pre-excitation examined by us (v. fig. 63 a—b).

F. Congenital defects

No definite statements can as yet be made regarding the changes in the Ekyg curves with these defects. This is partly because it is at times difficult to determine the various types either clinically or roentgenologically and partly because our series of the different types of defects are hitherto not sufficiently large. When, however, it is a question of making a differential diagnosis between a congenital and an acquired defect, an Ekyg can provide valuable information. The electrokymographic characteristics of the acquired defects disappear dependent on the extent of the superimposed valvular lesion. Moreover, an enlargement of the right ventricle is often a partial phenomenon in a large number of congenital defects. This enlargement is easily visible.

SUMMARY

The writers describe an electrokymograph constructed by them and give an account of its properties. A survey is made of the relevant anatomical and physiological data. A special section is devoted to the electrokymographic curves from various parts of the heart in normal subjects. A description is given of typical electrokymograms in a large number of pathological processes of the heart.

ZUSAMMENFASSUNG

Verff. beschreiben einen von ihnen konstruierten Elektrokymographen und dessen Eigenschaften. Für die Elektrokymogramme bedeutungsvolle anatomische und physiologische Daten werden angeführt. Ein besonderes Kapitel behandelt die normalen Elektrokymogrammkurven aus verschiedenen Partien des Herzens. Typische Elektrokymogramme bei zahlreichen krankhaften Vorgängen im Herzen werden beschrieben.

RÉSUMÉ

Les auteurs décrivent un électrokymographe construit par eux et indiquent ses propriétés. Ils passent en revue des données anatomiques et physiologiques présentant de l'importance pour l'électrokymographie. Un chapitre spécial est consacré aux courbes électrokymographiques normales de divers segments du cœur. Description d'électrokymogrammes typiques d'un grand nombre de processus pathologiques du cœur.

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FROM THE DEPARTMENT FOR CELL RESEARCH, KAROLINSKA INSTITUTET, STOCKHOLM, AND THE ROENTGEN DIAGNOSTIC DEPARTMENT OF PENSIONSSTYRELSENS SJUKHUS, NYNÄSHAMN, AND OF KAROLINSKA SJUKHUSET, STOCKHOLM, SWEDEN.

A METHOD FOR THE QUANTITATIVE ROENTGENOLOGICAL DETERMINATION OF THE AMOUNT OF CALCIUM SALTS IN BONE TISSUE[1]

Its Use in the Study of Calcium Reduction in the Phalanges of the Fingers in Chronic Polyarthritis

by

Arne Engström and *Sölve Welin*

Introduction

A reduction in the content of calcium salts of the bone tissue takes place in various diseases. It is of particular interest in chronic polyarthritis, in which the juxtaarticular reduction of calcium salts coincident with the periosteal reaction is a well-known reversible symptom in the initial stage. Under certain conditions the estimation of the reduction of calcium salts can be of particular significance. This is, for example, the case when the clinical picture is very vague. A decrease in the calcium salts, as is also the case with periosteal irritation, can be the first and only objective symptom of chronic polyarthritis. In such instances roentgenological examination confirms the clinical suspicion.

Furthermore, it is important that by repeated roentgenological examinations it is possible to follow the content of calcium salts and thus to judge the course of the disease. If the content of calcium salts increases, this is namely a sign of improvement. Finally, a certain type of severe chronic polyarthritis exists in which there is a pronounced decrease in the calcium salts in a number of joints even at the initial stage. In such cases, roentgenological confirmation of this fact indicates that the process is of a more pronounced type.

A definite estimation of the content of calcium salts is thus of very great significance. This problem has long been the object of interest and many theories have been forthcoming in respect of its cause and pathogenesis. The quantitative relationship between the local reduction of the

[1] Submitted for publication, April 29, 1949.

content of calcium salts and the changes visible on the roentgen picture have not, however, as yet been the object of any larger investigations. It is true that RIEDER (1936) stated that the calcium decrease must have reached a definite degree before it could be demonstrated roentgenologically and according to the investigations of LANDOFF, amongst others, a decrease of up to 10—15 per cent is necessary for a definite roentgenological diagnosis. LANDOFF supports his theory on gravimetric studies.[1]

Since the changes visible on the roentgen picture have hitherto only been assessed subjectively and have thus to a greater or lesser degree depended on the experience of the individual radiologist, the value of roentgen methods in this respect have been considered in many quarters to be fairly limited, particularly since there are normally such large variations in the osseous structure.

The object of the present study was to establish an objective basis for the estimation of the content of calcium salts and also to make possible a definite diagnosis even of less pronounced degrees in its reduction. A series of quantitative measurements of the content of calcium salts were therefore made in the different finger phalanges both of healthy middle-aged individuals, representing a very wide range of occupations, and of a number of middle-aged persons suffering from rheumatic disorders.

It is to be noted that in the present study the calcium content was measured per *unit volume* and not per *unit weight* as was the case in earlier gravimetric methods. This is obviously a suitable procedure since it is the quantity of calcium salts per unit volume that conditions the contrast in the roentgen picture.

The Material

The material consists of the following: 1) 160 radiograms from thumbs and index fingers, photographed from two planes perpendicularly to each other, of ten men and ten women (Cases 1—20) who on the occasion of examination felt entirely healthy and had never suffered from any joint complaints; 2) 160 radiograms from corresponding parts of the skeleton of a similar number of men and women (Cases 21—40) who were admitted to Pensionsstyrelsens sjukhus at Nynäshamn on the grounds of rheumatic complaints. From a clinical point of view these patients represent various degrees of severity of chronic polyarthritis.

From a practical aspect, the cases of chronic polyarthritis are classified at the forementioned hospital into three degrees of severity. As table 1 shows, the main considerations in this classification are the

[1] In order to measure the roentgen density on cystine calculi, RENANDER made a quantitative photographic photometric determination of the roentgen absorption.

number of joints affected, *oedema*, *disturbances in function*, *other clinical symptoms* such as muscular atrophy, effect on the general state of health, etc., the *roentgenological changes* and the *sedimentation rate*.

According to the foregoing classification — which is obviously to a great extent subjective — the material is distributed as follows:

Group I	Group II	Group III
Cases no. 29	Cases no. 21	Cases no. 22
» » 31	» » 24	» » 23
» » 35	» » 25	» » 26
	» » 27	» » 33
	» » 28	» » 34
	» » 30	» » 36
	» » 32	» » 37
	» » 38	» » 39
	» » 40	

The Method

Fine-grained film emulsions without intensifying screens, and the same voltage — 44 kV — were used throughout. The films were developed as uniformly as possible. An additional control was made of the films in that only those were used in which the roentgen intensity was even over the whole film.

As a standard with which the roentgen absorption in the bones could be compared, three aluminium step-wedges of varying thickness were photographed simultaneously on each film (cf. fig. 1).

The density at fixed points in the thumb and index finger were compared with the steps in absorption caused by the wedges. The density was determined with the densitometer described earlier by ENGSTRÖM, WEGSTEDT and WELIN (fig. 2).

When measuring the density the light scattering in the film emulsion can be neglected as the photographic film is diffusely illuminated in the apparatus. Thus it is not necessary to have a wide

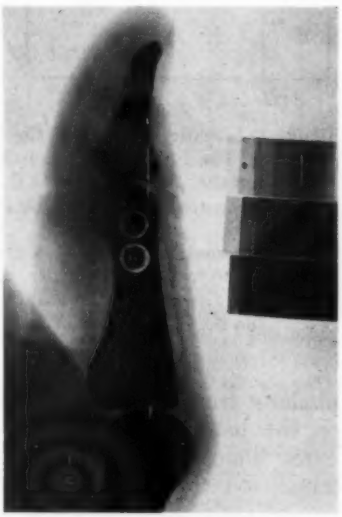

Fig. 1. Roentgenogram of a thumb with the accompanying three step-wedges. Each wedge has five steps.

angle of the light collecting pinhole. Furthermore, in this investigation where in all measurements the standard step-wedge also was measured, the light scattering in the film emulsion can be completely ignored. For absolute measurements, however, where a parallel beam of light is used, the collecting angle has to be wide. In these cases a hollow cone is inserted in place of the pinhole in the densitometer.

The density was measured within a surface of 2.0 mm² and within the areas indicated by circles in fig. 1. These were chosen centrally in the phalanges at a distance of 1/6 and 1/3 respectively of the length of the

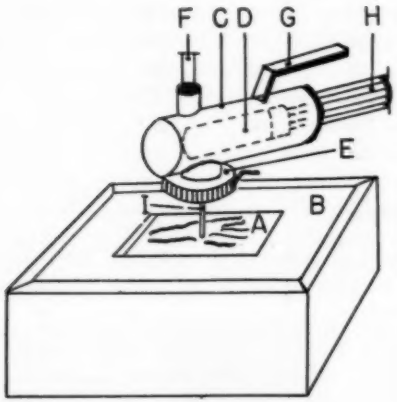

Fig. 2.

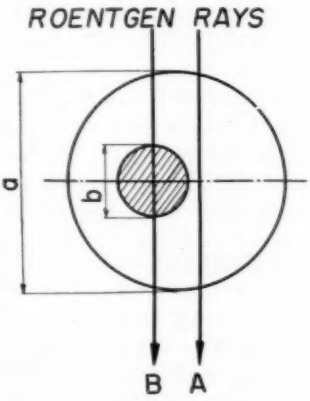

Fig. 3.

Fig. 2. Schematic drawing of the densitometer used.
A. The film to be measured photometrically. B. The illumination box. C. Cover for the photomultiplier. D. Photomultiplier tube. E. Shutter. F. Leads to the measuring instrument. G. Handle. H. Leads for the high-voltage source. I. Pinhole.

Fig. 3. Schematic drawing of a cross-section of a finger.
a. the width of the finger. b. the width of the bone. Both are measured along the direction of the beam used. A. the absorption of the roentgen rays through the bone. B. the absorption through the bone and soft tissues (cf. equation 1).

phalanx from the next adjacent joint surface. In the thumb they were on the basal phalanx nearest to the interphalangeal joint and in the index finger on either side of the proximal interphalangeal joint. Simultaneously, the absorption of the soft tissues was measured at a point immediately ventral of the corresponding area of measurement within the bone.

In order to determine the roentgen absorption per unit volume of bone, thus making possible a direct comparison between the different

substances, a correction must be introduced both for the absorption in the over- and under-lying soft tissues and for the thickness of the bone itself. This was made by means of direct measurements with a millimeter scale of the breadth of the soft tissues and of the bone on a roentgen picture taken at an angle of 90° to that on which the measurements were made (cf. the schematic fig. 3).

The measurements were made as follows. The light absorption was first measured within the roentgen absorption image caused by the step-wedges on the film. In the majority of cases the intermediate absorption was used. The photometer deflection from each wedge was plotted in a curve as a function of the thickness of the wedge represented by the number of aluminium plates piled on top of each other. The appearance of the curve is seen in fig. 4, which refers to Case 23, and is one of the 160 curves drawn. It was necessary to plot such a curve for each roentgen film on which density measurements were made.

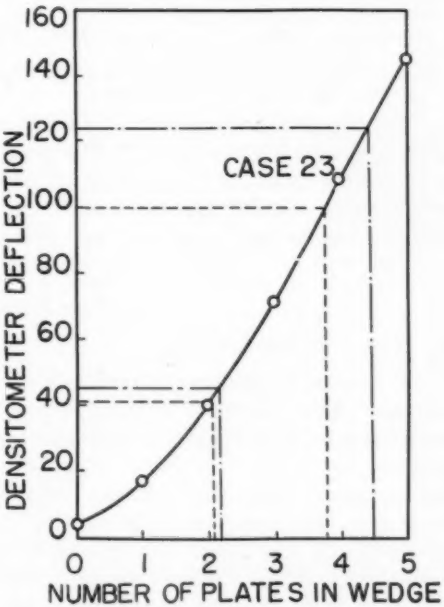

Fig. 4. Calibration curve showing the photometer deflections for the different wedge-steps as a function of their thickness. Each of the measurements in the bone and soft tissues of the thumb of Case 23 is plotted on the curve.

The photometer deflections for the various measuring points in the bones were registered. By means of the diagram (cf. fig. 4) for the roentgen films in question, it is possible to transfer the different absorptions both for the bone and for the soft tissues to the thickness of aluminium that is equivalent in respect of the absorption capacity. The absorption in the bones and in the soft tissues is thereby obtained in step-wedge equivalents and the different values are thus directly comparable.

The correction for the absorption of the soft tissues and for the thickness of the bone is calculated according to the equation in the following. Under the conditions present, the absorption in the bone obtained with

this formula is expressed in a quantity directly proportionate to the amount of calcium salts. The different values are thus directly comparable. The designations in the formula refer to fig. 3. *B.* and *A.* are the absorption capacity for the bone + the soft tissues and the soft tissues alone respectively, expressed as the number of step-wedge equivalents. *a* and *b* are the breadth of the whole finger and of the bone respectively, expressed in millimeters. $a - b$ is thus the total thickness of the over- and underlying soft tissues. The corrected roentgen absorption (X) per millimeter of bone is thus:

$$X = \frac{B - A \cdot \frac{a - b}{a}}{b}$$

The figure for the content of calcium salts per mm. of bone obtained at each measuring point will be the mean figure for the roentgen absorption in the entire bone. This mean figure will therefore be larger in the case of a bone with a thick cortex than in that of a bone with a thin cortex or with a decrease in the content of calcium salts.

The Results

A. The Normal Material

The normal material consisted of radiograms from 10 men and 10 women. They were divided into two groups of equal size and were examined on two different occasions. The conditions were otherwise as uniform as possible in order to allow further control of the accuracy of the measurements. The results obtained are shown in tables 2—9. Tables 2—5 give the measurements on the thumbs. The left half of the tables shows the figures from the distal measuring area, taken centrally in the basal phalanx of the thumb at a distance of $^1/_6$ of the length of the phalanx from the interphalangeal joint. The right half of the tables contains the measurement figures from the proximal area, $^1/_3$ of the length of the phalanx distant from the same joint. In tables 6—9, which show the measurement series from the index fingers, the areas are the following: Series 1: the most distal measurement area on the middle phalanx at a distance of $^1/_3$ of the length of the phalanx from the proximal interphalangeal joint. Series 2: at a distance of $^1/_6$ of the length of the phalanx from the same joint. Series 3 and 4 are from corresponding areas in the basal phalanx with series 3 from the nearest joint.

The tables give the thickness of the bone (b) and of the over- and underlying soft tissues (a—b) at the site of the measurements (cf. equation 1). In the next column are seen the absorption figures in those parts of the bone (B) marked with circles in fig. 3. The following column shows

Table 1.

Chronic Polyarthritis — Degree of Severity

	Group I	Group II		Group III	
	Slight	Moderately severe		Severe	
				Older advanced	Fresh-malignant
No. of joints affected	few	few	several	several	several
Oedema, etc.	slight	considerable	considerable	considerable	considerable
Function	good	considerably impaired	good—slightly impaired	considerably impaired	considerably impaired
Other clinical symptoms	general condition good	—	—	muscular atrophy	muscular atrophy (rapid onset)
Roentgenological changes	0—slight	moderate—considerable	slight	considerable	decalcification (rapid onset)
Sedimentation rate	normal—moderate	high	moderate—high	moderate—high	extremely—high

the figures for the absorption in the soft tissues (A). The corrected absorption figure for the bone, calculated according to the formula on p. 6, is given in the last column. The mean figure and the scattering are also calculated. Table 10 shows the mean figures and the statistical variations assembled from tables 2—9.

B. The Pathological Material

An account of the measurements on this material, also consisting of radiograms from 10 men and 10 women, is given in tables 11—14, compiled in the same way as for the normal material. The clinical degree of severity of the disease according to table 1 is also noted in each case.

If the results of these measurements in the various parts of the fingers are compared with the corresponding mean figures in the normal material, it is found that in approximately half of the cases the amount of calcium salts in the bone, given in the number of step-wedge equivalents, is below the limits of error for the normal material. The reduction is thus statistically significant.

The pathological material is selected insofar as all the patients, on the occasion of the examination suffered or had suffered from affections of the finger joints. If the figures obtained for these cases are compared with the clinical classification according to the forementioned schema, very

Table 2.

1. Measurements of the absorption of roentgen rays in the thumbs in the normal male material.

Case	The measuring point situated distal in the basal phalanx					The measuring point situated proximal in the basal phalanx				
	Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
			Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
1 L	12 mm	11 mm	3.80	2.15	2.31	9.5 mm	13 mm	4.15	2.00	3.14
R	13 »	12 »	4.15	1.90	2.46	10 »	13.5 »	4.35	1.75	3.35
2 L	14 »	12 »	4.10	2.10	2.21	10.5 »	15.5 »	4.60	1.95	3.29
R	14 »	12 »	4.50	2.00	2.56	11 »	15 »	4.70	2.00	3.21
3 L	14 »	14 »	4.35	2.40	2.26	12 »	15 »	4.80	2.30	2.52
R	14 »	14 »	4.75	2.15	2.62	12 »	16 »	4.95	2.15	3.12
4 L	13 »	13 »	4.95	1.90	3.04	11 »	14 »	5.00	1.80	3.62
R	14 »	11 »	5.35	2.20	3.12	11 »	13 »	4.90	2.15	3.44
5 L	13 »	12.5 »	3.90	2.00	2.28	10 »	15 »	4.60	2.10	3.25
R	13 »	13 »	4.20	1.90	1.88	9 »	17 »	4.80	2.20	2.53
			Mean value: 2.47 ± 0.38.					Mean value: 3.15 ± 0.36.		

Table 3.

2. Measurements of the absorption of roentgen rays in the thumbs in the normal male material.

Case	The measuring point situated distal in the basal phalanx					The measuring point situated proximal in the basal phalanx				
	Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
			Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
6 L	13 mm	12 mm	4.50	1.95	3.29	10.5 mm	13.5 mm	4.55	1.85	3.34
R	12 »	13 »	4.30	1.90	2.76	10.5 »	13.5 »	4.15	1.65	2.97
7 L	14 »	13 »	4.05	1.75	2.91	11 »	15 »	4.40	1.75	3.08
R	15 »	12 »	4.55	2.20	2.38	11.5 »	16.5 »	4.85	1.95	3.18
8 L	15 »	12 »	5.20	2.50	2.73	12 »	14 »	4.95	2.30	3.09
R	14.5 »	12.5 »	5.50	2.35	3.05	11 »	15 »	5.10	2.25	3.47
9 L	14.5 »	10.5 »	5.00	1.85	2.92	10 »	14 »	5.60	1.75	4.56
R	14 »	11 »	5.00	2.00	2.94	10 »	14 »	5.35	1.70	4.36
10 L	14 »	12 »	4.85	2.10	2.77	10 »	15 »	4.90	1.85	3.78
R	14 »	12 »	5.45	2.15	3.07	10 »	16 »	5.20	2.05	3.94
			Mean value: 2.88 ± 0.25.					Mean value: 3.58 ± 0.56.		

good agreement is found in respect of the cases in group 3. Five of these eight patients showed pathological figures at all the 12 sites of measurement. Of the three remaining patients, one (case 26) had 11 pathological and 1 normal figure, another (Case 39) 10 pathological and 2 normal figures and the third (Case 23) pathological figures at all the sites measured

Table 4.

1. Measurements of the absorption of roentgen rays in the thumbs in the normal female material.

Case	The measuring point situated distal in the basal phalanx					The measuring point situated proximal in the basal phalanx				
	Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
			Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
11 L	11 mm	11 mm	4.70	1.65	3.52	9 mm	13 mm	5.50	1.60	5.06
R	11 »	11 »	5.10	1.95	3.76	9 »	13 »	5.45	1.85	4.85
12 L	12 »	10 »	5.05	1.95	3.47	10 »	13 »	4.95	1.70	3.99
R	12 »	11 »	5.05	1.95	3.43	10 »	13 »	4.95	1.65	4.01
13 L	11 »	8 »	3.65	1.20	2.85	8 »	11 »	3.90	1.10	4.07
R	10.5 »	8 »	3.90	1.10	3.27	8 »	10 »	4.30	0.95	4.12
14 L	10 »	12 »	3.40	0.85	2.93	8.5 »	14 »	4.10	0.75	4.27
R	10 »	11 »	3.35	1.20	2.72	8 »	14 »	3.80	1.00	3.95
15 L	13 »	9 »	4.05	1.50	2.64	9 »	12 »	4.30	1.35	3.92
R	13 »	9 »	4.50	1.95	2.84	10 »	12 »	4.90	1.95	3.84
			Mean value: 3.14 ± 0.39.					Mean value: 4.21 ± 0.41.		

Table 5.

2. Measurements of the absorption of roentgen rays in the thumbs in the normal female material.

Case	The measuring point situated distal in the basal phalanx					The measuring point situated proximal in the basal phalanx				
	Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
			Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm boen
16 L	11 mm	9 mm	4.10	1.65	3.05	8 mm	12 mm	4.15	1.55	4.03
R	11 »	9 »	3.70	1.40	2.79	9 »	11 »	3.95	1.40	3.53
17 L	11 »	9 »	3.80	1.60	2.79	8 »	12 »	4.05	1.55	3.90
R	12 »	9 »	3.45	1.40	2.37	7 »	13 »	3.55	1.45	3.72
18 L	11 »	10 »	3.75	1.40	2.86	9 »	13 »	4.15	1.25	3.79
R	11 »	10 »	4.25	1.25	3.32	9 »	12 »	4.55	1.20	4.30
19 L	11 »	11 »	4.30	1.75	3.12	9 »	13 »	5.10	1.80	4.46
R	11 »	11 »	4.00	1.35	2.96	9 »	14 »	4.35	1.35	3.99
20 L	11 »	9 »	2.35	1.60	1.48	8 »	12 »	4.25	1.50	4.19
R	11 »	9 »	3.90	1.80	2.81	7.5 »	12.5 »	5.00	1.70	5.27
			Mean value: 2.76 ± 0.51.					Mean value: 4.12 ± 0.50.		

in the left index finger and at the proximal juxta-articular area in the right index finger.

In groups I and II the results showed that entirely normal figures were present in certain cases, whereas in the others there were figures suggestive of a reduction in the content of calcium salts. This was to be

Table *1. Measurements of the absorption of roentgen rays*

Case	The measuring point situated most distal in the middle phalanx					The measuring point situated distal in the middle phalanx				
	Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
			Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
1 L	12 mm	10 mm	3.90	1.75	2.59	14 mm	9 mm	4.05	1.80	2.39
R	10 »	14 »	3.55	1.70	2.56	15 »	10 »	3.90	1.85	2.11
2 L	11 »	10 »	3.25	1.65	2.22	14 »	8 »	4.05	1.65	2.46
R	10.5 »	10.5 »	3.50	1.85	2.41	14 »	9 »	3.95	2.00	2.27
3 L	12 »	12 »	3.05	1.85	1.80	15 »	9 »	3.35	2.00	1.73
R	11 »	12 »	3.60	2.05	2.40	14 »	10 »	3.40	2.10	1.79
4 L	10.5 »	11.5 »	3.65	1.90	2.54	14 »	9 »	4.45	1.95	2.62
R	9 »	12 »	3.20	1.85	2.39	14 »	9 »	3.85	2.00	1.83
5 L	11 »	11 »	3.40	1.65	2.32	15 »	7 »	3.25	1.70	1.81
R	10 »	11 »	4.30	1.90	3.31	14 »	9 »	3.30	2.05	1.99
			Mean value: 2.45 ± 0.37.					Mean value: 2.10 ± 0.31.		

Table *2. Measurements of the absorption of roentgen rays*

Case	The measuring point situated most distal in the middle phalanx					The measuring point situated distal in the middle phalanx				
	Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
			Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
6 L	10 mm	10 mm	3.30	1.35	2.63	12 mm	9 mm	3.00	1.45	1.97
R	10 »	10 »	3.15	1.35	2.48	13 »	8 »	2.95	1.45	1.85
7 L	11 »	12 »	3.40	1.50	2.38	16 »	8 »	3.75	1.65	2.00
R	10.5 »	10.5 »	3.50	1.40	2.67	14 »	10 »	3.50	1.50	2.05
8 L	12 »	10 »	4.30	2.10	2.71	15 »	8 »	4.80	2.15	2.80
R	11 »	12 »	3.80	2.00	2.58	15 »	8 »	4.15	2.10	2.28
9 L	11 »	11 »	4.30	2.00	3.00	15 »	8 »	4.55	2.10	2.54
R	9.5 »	12.5 »	4.25	1.35	3.17	14.5 »	8.5 »	3.80	1.40	2.28
10 L	11 »	12 »	3.65	1.75	2.49	14 »	9 »	3.55	1.95	2.00
R	11 »	11 »	4.05	1.60	2.96	14 »	9 »	3.70	1.75	2.15
			Mean value: 2.71 ± 0.26.					Mean value: 2.19 ± 0.26.		

expected since, clinically, the symptoms were not so pronounced as in group III. With this method there is, however, a possibility of demonstrating whether the pathological condition is so pronounced as to cause a decrease in the content of calcium salts.

In addition, it was found that the reduction of calcium salts was not confined to the bones adjacent to the joints but that the diaphyses were

6.

in the index fingers in the normal male material.

The measuring point situated proximal in the basal phalanx					The measuring point situated most proximal in the basal phalanx				
Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
		Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
12 mm	11 mm	4.20	1.45	2.92	10 mm	14 mm	4.65	1.45	3.80
11 »	12 »	4.40	1.40	3.32	10.5 »	13.5 »	4.35	1.55	3.30
13 »	12 »	5.00	1.85	3.17	11 »	15 »	5.65	1.80	4.20
12 »	13 »	4.85	1.60	3.35	12 »	14 »	5.05	1.65	3.46
15 »	9 »	5.70	2.15	3.26	12 »	12 »	5.50	2.25	3.63
14.5 »	10.5 »	5.55	2.10	3.23	13 »	12 »	5.35	2.00	3.48
14 »	10 »	5.20	2.00	3.12	11 »	13 »	5.75	1.90	4.25
14 »	9.5 »	5.05	1.50	3.16	11 »	13 »	5.65	1.45	4.41
12 »	12 »	4.85	1.80	3.28	12 »	13 »	5.90	1.90	4.10
12 »	13 »	4.70	1.95	3.06	11 »	14 »	5.80	1.70	4.40
		Mean value: 3.19 ± 0.13.					Mean value: 3.90 ± 0.45.		

7.

in the index fingers in the normal male material.

The measuring point situated proximal in the basal phalanx					The measuring point situated most proximal in the basal phalanx				
Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
		Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
12 mm	11 mm	5.50	2.00	3.78	10.5 mm	12.5 mm	5.80	2.15	4.42
12 »	14 »	4.85	2.00	3.14	11 »	15 »	5.55	2.05	3.98
13 »	10 »	4.75	1.85	3.20	12 »	11 »	5.70	2.05	3.93
13 »	11 »	4.85	2.25	2.92	11 »	14 »	5.60	2.25	4.04
14 »	12 »	4.60	2.00	2.62	13 »	13 »	5.30	1.90	3.34
14 »	12 »	4.80	2.15	2.63	12 »	14 »	5.00	2.15	3.26
12 »	12 »	5.85	2.25	4.20					
12 »	12 »	4.10	2.10	2.54	11 »	13 »	5.20	2.25	3.62
12 »	12 »	4.50	1.85	3.00	11 »	14.5 »	5.85	2.00	4.39
12 »	12 »	4.55	2.10	2.92	12 »	13 »	5.50	2.15	3.76
		Mean value: 3.10 ± 0.53.					Mean value: 3.87 ± 0.41.		

also involved. It is generally considered that the decrease in the amount of calcium salts starts in the immediate vicinity of the joints. The results in our material appear to indicate to some extent that the reduction may be diffuse. The present study does not, however, permit any definite answer to this question which can only be solved on the basis of a larger material. This also applies to the variations in the calcium content during

Table 1. *Measurements of the absorption of roentgen rays*

Case	The measuring point situated most distal in the middle phalanx					The measuring point situated distal in the middle phalanx				
	Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
			Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
11 L	8 mm	11 mm	4.15	1.15	2.80	11 mm	9 mm	3.85	1.15	2.96
R	9 »	12 »	4.30	1.75	3.60	12 »	9 »	4.30	1.85	2.92
12 L	10 »	11 »	3.95	1.80	3.00	12 »	9 »	4.45	1.80	3.05
R	9 »	12 »	3.95	1.75	3.31	14 »	8 »	4.45	1.75	2.72
13 L	8 »	9 »	3.10	1.00	3.21	11 »	7 »	2.90	1.00	2.28
R	8 »	9 »	3.50	1.30	3.49	12 »	6 »	3.40	1.30	2.47
14 L	9 »	10 »	2.80	1.15	2.43	12 »	7.5 »	3.20	1.25	2.27
R	9 »	10 »	3.00	1.40	2.51	13 »	7 »	3.30	1.40	2.24
15 L	9 »	10 »	3.00	1.25	2.60	13 »	8 »	4.05	1.35	2.71
R	9 »	10 »	3.25	1.30	2.84	11 »	8 »	3.45	1.35	2.62
			Mean value: 2.98 ± 0.40.					Mean value: 2.62 ± 0.30.		

Table 2. *Measurements of the absorption of roentgen rays*

Case	The measuring point situated most distal in the middle phalanx					The measuring point situated distal in the middle phalanx				
	Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
			Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
16 L	8 mm	9 mm	3.10	1.25	3.06	12 mm	6 mm	3.20	1.30	2.33
R	8 »	10 »	3.25	1.20	3.23	11 »	8 »	3.25	1.20	2.30
17 L	7 »	10 »	3.20	1.25	3.52	12 »	6 »	3.10	1.35	2.23
R	8 »	10 »	3.15	1.50	2.80	12 »	7 »	3.35	1.60	2.50
18 L	8 »	11 »	3.30	1.25	3.24	12 »	8 »	3.40	1.20	2.43
R	8 »	11 »	3.50	1.30	3.42	11 »	8 »	3.65	1.30	2.83
19 L	10 »	9 »	2.95	1.25	2.36	12 »	7 »	3.95	1.25	2.91
R	9 »	9 »	2.80	1.35	2.36	12 »	7 »	3.10	1.40	2.18
20 L	7 »	11 »	3.70	1.10	4.33	12 »	7 »	2.85	1.15	2.02
R	8 »	10 »	3.65	1.45	2.30	12 »	7 »	3.15	1.55	2.15
			Mean value: 3.06 ± 0.63.					Mean value: 2.39 ± 0.29.		

treatment of polyarthritis. It can, however, already be pointed out that in one case, where on admission to hospital the joints were severely affected but showed considerable improvement after treatment, the content of calcium salts was practically normal on discharge from hospital. (Case R. F. 368/48, which is not included in the present material.)

8.

in the index fingers in the normal female material.

The measuring point situated proximal in the basal phalanx					The measuring point situated most proximal in the basal phalanx				
Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
		Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
11 mm	11 mm	5.25	1.40	5.18	9 mm	14 mm	5.80	1.40	5.51
10 »	13 »	4.70	1.90	3.63	9 »	14.5 »	4.85	2.00	4.04
11 »	12 »	5.25	1.85	3.89	10 »	14 »	5.85	1.85	4.77
12 »	10 »	5.35	1.80	3.78	11 »	12 »	6.00	1.90	4.56
11 »	7 »	3.95	1.00	3.24	8 »	10 »	4.40	1.05	4.85
10 »	9 »	4.75	1.35	4.11	9 »	10 »	4.60	1.40	4.30
10.5 »	10 »	4.10	1.25	3.34	10 »	11 »	4.75	1.30	4.06
11 »	10 »	4.35	1.40	3.36	9 »	13 »	5.20	1.50	4.80
11 »	9 »	4.55	1.80	3.40	10 »	11 »	5.25	1.80	4.31
12 »	9 »	4.50	1.40	3.25	10 »	12 »	5.20	1.55	4.35
		Mean value: 3.72 ± 0.63.					Mean value: 4.56 ± 0.44.		

9.

in the index fingers in the normal female material.

The measuring point situated proximal in the basal phalanx					The measuring point situated most proximal in the basal phalanx				
Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
		Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
11 mm	8 mm	3.90	1.40	3.10	8 mm	12 mm	3.95	1.50	3.80
9 »	11 »	4.25	1.60	3.74	9 »	11 »	4.75	1.60	4.30
11 »	8 »	3.95	1.35	3.07	9 »	10 »	4.50	1.45	4.15
11.5 »	7.5 »	3.80	1.50	2.79	9 »	11 »	4.45	1.55	3.88
10 »	11 »	4.55	1.10	3.97	9.5 »	12.5 »	4.00	1.15	3.52
9.5 »	10.5 »	5.35	1.45	4.82	10 »	12 »	5.15	1.60	4.23
9.5 »	10.5 »	5.05	1.60	4.45	9.5 »	10.5 »	5.15	1.65	4.75
11 »	9 »	4.30	1.40	3.32	9.5 »	12.5 »	5.00	1.60	4.30
11 »	8 »	3.75	1.20	2.95	8 »	11 »	5.25	1.35	5.12
11 »	8 »	3.65	1.55	2.73	9 »	11 »	4.85	1.55	4.44
		Mean value: 3.49 ± 0.72.					Mean value: 4.20 ± 0.47.		

Discussion

In order to judge correctly the figures presented in tables 2—14 the various sources of error that can affect the results will be discussed.

The first condition for accurate results is that the *roentgen intensity is even over the whole film*. This was controlled by the measurement of the

Table 10.

Mean figures of the normal material.

Measuring point	Male		Female	
	Series 1	Series 2	Series 1	Series 2
Thumb dist.	2.47 ± 0.38	2.88 ± 0.25	3.14 ± 0.39	2.76 ± 0.51
Thumb prox.	3.15 ± 0.36	3.58 ± 0.56	4.21 ± 0.41	4.12 ± 0.50
Measuring point	**Male**		**Female**	
	Series 1	Series 2	Series 1	Series 2
Index finger most dist.	2.45 ± 0.37	2.71 ± 0.26	2.98 ± 0.40	3.06 ± 0.63
Index finger dist.	2.10 ± 0.31	2.19 ± 0.26	2.62 ± 0.30	2.39 ± 0.29
Index finger prox.	3.10 ± 0.53	3.19 ± 0.13	3.72 ± 0.63	3.49 ± 0.72
Index finger most prox.	3.87 ± 0.41	3.90 ± 0.45	4.56 ± 0.44	4.20 ± 0.47

Table 11.

1. Measurements of the absorption of roentgen rays in the thumbs in the pathological male material.

Case	Clinical group	The measuring point situated distal in the basal phalanx					The measuring point situated proximal in the basal phalanx				
		Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
				Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
21 L	II	14 mm	12 mm	4.00	2.40	2.06	12 mm	13 mm	3.50	2.20	1.97
R		14 »	13 »	4.10	2.25	2.17	12 »	14 »	4.20	2.25	2.49
22 L	III	13 »	14 »	3.80	2.35	1.97	12 »	14.5 »	3.45	1.70	2.10
R		15 »	16 »	3.55	2.20	1.61	13 »	16 »	3.25	2.00	1.65
23 L	III	14 »	11 »	3.75	2.05	2.04	11 »	14 »	4.45	2.15	2.95
R		15 »	11 »	4.35	1.95	2.35	11 »	14 »	4.75	2.10	3.25
24 L	II	14 »	10 »	3.85	1.70	2.24	11 »	12 »	3.90	1.60	2.78
R		15 »	8 »	4.15	0.85	2.57	11 »	11 »	3.80	1.10	2.95
25 L	II	14 »	11 »	4.25	1.80	2.46	12 »	13 »	4.60	1.90	3.01
R		14 »	11 »	4.45	2.20	2.48	12 »	12 »	4.60	2.10	2.96
26 L	III	13 »	13 »	2.90	1.90	1.50	10 »	15 »	3.05	1.80	1.97
R		13 »	13 »	3.40	2.15	1.79	11 »	15 »	3.80	2.20	2.30
27 L	II	12 »	12 »	3.50	1.30	2.38	9 »	16 »	4.10	1.35	3.62
R		11 »	14 »	4.35	2.00	2.94	9 »	16 »	5.55	2.10	4.70
28 L	II	14 »	8 »	2.75	1.60	1.55	11 »	9 »	2.35	1.70	1.44
R		14 »	10 »	3.15	1.45	1.82	12 »	11 »	2.80	1.60	1.69
29 L	I	14 »	12 »	3.45	1.85	1.85	10 »	16 »	4.15	1.80	3.04
R		14 »	13 »	4.25	1.80	2.42	10 »	15.5 »	4.75	1.80	3.72
30 L	II	14 »	10 »	3.90	1.95	2.21	11 »	12 »	4.10	1.80	2.87
R		14 »	12 »	4.55	2.40	2.32	11 »	14 »	5.00	2.45	3.29

Table 12.

2. Measurements of the absorption of roentgen rays in the thumbs in the pathological female material.

Case	Clinical group	The measuring point situated distal in the basal phalanx					The measuring point situated proximal in the basal phalanx				
		Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
				Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
31 L	I	11 mm	7 mm	3.10	1.45	2.30	8 mm	10 mm	3.50	1.35	3.45
R		11 »	8 »	3.40	1.30	2.53	9 »	10 »	3.75	1.35	3.42
32 L	II	11 »	10 »	3.45	1.40	2.52	9 »	12 »	4.50	1.60	3.97
R		11 »	11 »	4.05	2.05	2.75	8 »	14 »	4.85	2.05	4.43
33 L	III	11 »	9 »	2.40	1.10	1.73	10 »	10 »	3.10	1.35	2.43
R		12 »	9 »	2.25	1.50	1.39	9 »	12 »	2.80	1.55	2.61
34 L	III	11 »	11 »	2.95	1.40	1.97	10 »	12 »	3.35	1.40	2.58
R		12 »	11 »	2.75	1.45	1.67	10 »	12 »	3.20	1.55	2.35
35 L	I	12 »	13 »	3.20	1.95	1.84	9 »	16 »	4.15	1.65	3.44
R		13 »	11 »	4.25	1.85	2.62	9 »	14 »	4.90	2.00	4.19
36 L	III	12 »	10 »	3.25	1.60	2.12	9 »	12 »	3.80	1.70	3.29
R		12 »	9 »	3.05	1.80	1.90	9.5 »	11 »	3.55	1.60	2.84
37 L	III	12 »	10 »	3.30	1.65	2.12	9.5 »	13.5 »	3.60	1.85	2.65
R		12 »	10 »	3.40	1.80	2.15	10 »	12 »	3.55	1.80	2.57
38 L	II	12 »	12 »	2.95	1.50	1.83	9 »	14 »	3.20	1.60	2.48
R		12 »	11.5 »	3.50	2.00	2.10	9 »	14 »	3.75	2.00	2.81
39 L	III	12 »	10 »	3.20	1.35	2.16	9 »	13 »	4.30	1.35	3.89
R		12 »	10 »	3.75	1.85	2.38	9 »	13 »	4.50	1.95	3.72
40 L	II	12 »	9 »	2.60	1.30	1.71	10 »	12 »	3.50	1.30	2.79
R		12 »	10 »	3.50	1.70	2.27	11 »	12 »	3.60	1.60	2.51

density in a free area, *i. e.* in which neither the finger nor the step-wedge were photographed, and in the corner diagonally opposite to it. Only such films in which the photometric results (density) were the same in all corners were used.

Errors can also occur through *defective film emulsions*, but this would have been revealed in the control of the density, which was made on every film, as described above.

The *developing conditions* need not be standardized since a reference system in the form of a wedge-step was also photographed on each film. The only check that need be made is that the developments are even and that the films are properly developed. This is controlled by measuring the density on the free areas.

The error in the *measuring apparatus* used for the measurements of density was found to lie below 0.5 per cent in these relative measurements.

In addition, errors can possibly arise through the use of aluminium wedge-steps. Their roentgen-optical properties differ from those of bone. It could thus be envisaged that if there was an appreciable difference in the voltage used on the different occasions, a bone structure taken at the

Table

1. Measurements of the absorption of roentgen rays in

Case	Clinical group	The measuring point situated most distal in the middle phalanx					The measuring point situated distal in the middle phalanx				
		Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
				Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
21 L	II	11 mm	11 mm	3.05	1.40	2.14	16 mm	8 mm	3.60	1.45	1.95
R		11 »	10 »	2.40	1.45	1.56	15 »	8 »	3.20	1.45	1.66
22 L	III	11 »	10 »	2.30	1.65	1.37	15 »	7 »	2.75	1.85	1.44
R		10 »	12 »	2.45	1.55	1.60	14 »	12 »	2.95	1.75	1.53
23 L	III	11 »	10 »	2.65	1.35	1.82	15 »	7 »	2.90	1.55	1.61
R		10 »	10 »	3.35	1.60	2.55	13 »	8 »	3.55	1.70	2.23
24 L	II	10 »	9 »	2.85	1.50	2.14	14.5 »	8.5 »	2.90	1.50	1.54
R		12 »	8 »	2.70	1.70	1.67	15 »	7 »	3.45	1.85	1.94
25 L	II	11 »	10 »	3.15	1.40	2.26	15 »	7 »	3.40	1.55	1.94
R		11 »	11 »	3.40	1.75	2.29	15 »	8 »	3.70	1.85	2.03
26 L	III	10 »	11 »	2.30	1.30	1.62	13 »	9 »	2.05	1.35	1.15
R		10 »	12 »	2.50	1.85	1.49	14 »	9 »	2.50	1.95	1.45
27 L	II	9 »	11 »	3.20	1.45	2.67	14 »	7 »	3.55	1.45	2.18
R		9 »	11 »	3.15	1.50	2.59	14 »	7 »	3.60	1.75	2.14
28 L	II	11 »	11 »	2.20	1.25	1.43	16 »	6 »	2.65	1.25	1.44
R		11 »	10 »	2.65	1.65	1.63	16 »	6 »	3.15	1.65	1.79
29 L	I	10 »	10 »	2.55	1.65	1.73	14 »	8 »	2.95	1.80	1.63
R		11 »	10 »	2.85	1.80	1.82	14 »	8 »	3.40	1.80	1.97
30 L	II	11 »	8.5 »	2.50	1.25	1.78	15 »	6 »	3.20	1.50	1.84
R		10.5 »	9 »	2.60	1.60	1.77	15 »	6 »	2.80	1.75	1.53

lower voltage would not show exactly the same wedge-step equivalent as that obtained with a higher voltage. This is due to the fact that the mass absorption coefficients for aluminium and calcium salts do not run parallel in a large wave-length region (voltage region). This is presumably one of the sources of error in the method, since the voltage over the roentgen tube is controlled in the usual way with a voltmeter inserted in the primary circuit of the roentgen transformer. With different loads, the secondary voltage — the high voltage — can thus vary even if the voltmeter shows the same values. In order as far as possible to reduce this source of error, the roentgen tube was run with the same voltage and current in all the experiments and the same exposure time was used.

Errors can also occur in the correction for the absorption of the soft tissues. In the measurement film the bone lies excentrically in the finger. The absorption in the soft tissues is measured immediately adjacent to the bone. A small error can thus arise since the thickness of the finger is not exactly the same in those areas where 1) the soft tissues and 2) the soft tissues and the bone are measured.

Moreover, it is not possible to state definitely whether the soft tissues

13.

the index fingers in the pathological male material.

The measuring point situated proximal in the basal phalanx					The measuring point situated most proximal in the basal phalanx				
Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
		Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
14 mm	11 mm	5.15	2.10	3.01	12 mm	13 mm	4.95	2.10	3.52
13 »	11 »	4.50	1.95	2.78	11 »	13 »	4.45	2.05	3.04
15 »	10 »	3.25	2.15	1.53	11.5 »	14.5 »	3.05	1.90	1.73
13 »	11 »	3.60	1.75	2.00	11 »	13 »	3.20	1.90	2.19
13 »	11 »	3.90	1.85	2.32	11 »	14 »	4.45	2.00	3.02
14 »	10 »	4.30	2.05	2.46	12 »	13 »	5.30	2.15	3.48
15 »	8 »	4.40	1.65	2.55	12 »	11 »	4.75	1.75	3.26
12 »	12 »	4.55	2.30	2.82	12 »	13 »	4.55	2.30	2.80
15 »	9 »	4.75	1.80	2.72	11 »	13 »	5.80	1.95	4.30
14 »	11 »	4.65	1.95	2.71	11 »	13 »	5.20	2.00	3.74
12 »	14 »	3.00	1.60	1.79	10 »	16 »	3.70	1.70	2.65
12 »	13 »	3.70	2.20	2.13	10 »	16 »	5.30	2.30	3.88
11 »	13 »	5.15	1.90	3.75	11 »	12 »	5.60	2.00	4.15
13.5 »	10.5 »	4.30	2.10	2.50	10 »	15 »	5.60	1.65	4.61
14 »	9 »	3.55	2.05	1.96	13 »	10 »	3.90	2.05	2.32
13 »	10 »	3.25	1.80	1.90	13 »	10 »	3.90	1.80	2.40
13 »	11 »	4.20	1.75	2.62	9 »	15 »	5.30	1.75	4.75
12.5 »	10 »	4.95	2.00	3.21	12 »	12 »	5.00	2.00	3.33
13.5 »	8.5 »	3.95	1.60	2.46	11 »	12 »	4.15	1.70	2.96
14 »	9 »	4.40	2.10	2.55	11 »	12 »	4.65	2.10	3.23

in one projection have exactly the same absorption capacity as in the other. This error need not, however, affect the results to any appreciable extent.

In earlier studies with the object of correlating the roentgen findings with the degree of reduction in the content of calcium salts, gravimetric methods were used to determine the amount of calcium salts. With this method the content of calcium salts per unit weight of bone is obtained. Since, however, the contrast in the roentgenogram is conditioned by the amount of absorbing substance per volume unit the present writers consider it more correct to measure the amount of calcium salts in this way.

A further study of the material brings to light, in those cases in which the measurements showed a decrease in the content of calcium salts, the changes that have long been well-known, *i. e.* foci with a sparser structure, and a thinning and later a splitting of the cortex as well.

The method described in this paper appears to be suitable for the study of a series of problems in roentgenology in which it is desired to determine quantitatively the course of decalcification of the new formation of bone, *e. g.* in bone tumours and in the formation of calluses.

Table

2. Measurements of the absorption of roentgen rays in

Case	Clinical group	The measuring point situated most distal in the middle phalanx					The measuring point situated distal in the middle phalanx				
		Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
				Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
31 L	I	9 mm	7 mm	2.45	1.15	2.80	11 mm	6 mm	2.80	1.15	2.29
R		8 »	9.5 »	3.15	1.55	2.88	11 »	7 »	3.00	1.55	2.18
32 L	II	9 »	9 »	3.65	1.65	2.56	12 »	7 »	3.05	1.65	2.04
R		9 »	9 »	3.45	1.40	2.47	12 »	7 »	2.75	1.40	1.86
33 L	III	8 »	10 »	2.50	1.40	2.15	12 »	7 »	2.45	1.45	1.59
R		9 »	9 »	1.80	1.30	1.28	12 »	7 »	2.15	1.50	1.33
34 L	III	8 »	10 »	2.40	1.45	2.00	12 »	9 »	3.05	1.65	1.95
R		8.5 »	10 »	2.00	1.15	1.62	13 »	7 »	2.40	1.20	1.53
35 L	I	9 »	11 »	2.60	1.10	2.21	13 »	8 »	3.00	1.35	1.92
R		9 »	11 »	2.50	1.40	1.93	13 »	8 »	2.50	1.50	1.48
36 L	III	10 »	9 »	2.60	1.15	2.05	13 »	7 »	2.15	1.40	1.28
R		9 »	9 »	2.70	1.30	2.28	12 »	6 »	2.75	1.50	1.87
37 L	III	10 »	9 »	2.35	1.30	1.73	13 »	7 »	2.90	1.50	1.82
R		9 »	9 »	2.40	1.40	1.88	13 »	7 »	2.70	1.45	1.68
38 L	II	8 »	11 »	2.10	1.10	1.85	11 »	9 »	2.55	1.20	1.83
R		8 »	12 »	2.15	1.35	1.68	13 »	8 »	2.80	1.50	1.72
39 L	III	8 »	10 »	2.15	1.20	1.48	12 »	8 »	2.65	1.35	1.73
R		8.5 »	10 »	2.30	1.70	1.63	13.5 »	6.5 »	3.00	1.70	1.82
40 L	II	9 »	10 »	2.25	1.25	1.76	11 »	8 »	2.80	1.35	1.82
R		9 »	10 »	2.50	1.30	2.03	12 »	8 »	2.85	1.50	1.88

SUMMARY

A method for the quantitative determination of the amount of calcium salts in the bone tissues is described. By means of photographing simultaneously on the radiogram a reference system in the form of a series of aluminium step-wedges, it is possible to calculate the absorption in the different parts of the bone, expressed in units of the reference system.

The different sources of error inherent in the method are discussed.

The method is used to study the degree of reduction of calcium salts in patients with chronic polyarthritis. The figures obtained quantitatively are compared with the clinical picture. In the clinically advanced cases a good correlation is found between the degree of reduction of the calcium salts and the severity of the disease.

The method described appears to be suitable for the study of a number of problems in quantitative roentgen diagnostics.

ZUSAMMENFASSUNG

Eine Methode zur quantitativen Bestimmung der Menge der Kalziumsalze in Knochengewebe wird beschrieben. Gleichzeitige Aufnahme eines aus Aluminium-Stufenkeilen bestehenden Vergleichssystems im Röntgenbilde ermöglicht Berechnung der Absorption in den verschiedenen Partien des Knochens, in Einheiten des Vergleichssystems ausgedrückt.

Die dieser Methode anhaftenden verschiedenen Fehlerquellen werden besprochen.

14.

the index fingers in the pathological female material.

The measuring point situated proximal in the basal phalanx					The measuring point situated most proximal in the basal phalanx				
Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent			Breadth of the bone	Breadth of the soft tissue	Step-wedge equivalent		
		Bone + soft tissue	Soft tissue	Per mm bone			Bone + soft tissue	Soft tissue	Per mm bone
10 mm	8 mm	3.80	1.35	3.20	9 mm	10 mm	3.45	1.30	3.08
11 »	8 »	4.30	1.65	3.12	9 »	10 »	5.00	1.90	4.45
10 »	11 »	5.50	1.85	4.43	10 »	12 »	7.60	1.85	6.59
10 »	11 »	4.30	1.70	3.41	9 »	13 »	5.10	1.90	4.42
12 »	9 »	3.05	1.60	1.96	10 »	12 »	4.30	1.55	3.45
11 »	9 »	3.30	1.90	2.23	10 »	12 »	4.40	2.00	3.31
11 »	12 »	3.70	1.95	2.44	10 »	13 »	4.60	1.95	3.50
9 »	14 »	3.15	1.60	2.42	9 »	14 »	3.50	1.60	2.80
11 »	11 »	3.85	1.40	2.86	10 »	12 »	4.80	1.45	4.01
10 »	12 »	4.10	1.60	3.23	10 »	13 »	4.65	1.50	3.80
11 »	10 »	2.90	1.30	2.03	11 »	10 »	3.75	1.35	2.84
13 »	7 »	3.20	1.55	2.04	11 »	10 »	4.20	1.75	3.05
12 »	10 »	3.85	2.10	2.40	10 »	13 »	4.85	2.50	3.49
13 »	10 »	3.60	1.75	2.18	11 »	13 »	3.80	1.85	2.54
10 »	12 »	3.15	1.40	2.38	10 »	12 »	3.95	1.45	3.16
11 »	10 »	3.35	1.50	2.39	10 »	11 »	3.95	1.75	3.03
11 »	11 »	3.30	1.50	2.32	9 »	13 »	3.85	1.50	3.29
12 »	10 »	3.70	2.10	2.29	9 »	13.5 »	4.45	2.15	3.52
12 »	9 »	3.15	1.40	2.13	11 »	12 »	4.10	1.60	2.83
11 »	11 »	3.40	1.60	2.36	11 »	11 »	4.70	1.70	3.50

Die Methode wird zum Studium des Grades des Kalkschwundes bei Kranken mit chronischer Polyarthritis verwendet. Die erhaltenen quantitativen Werte werden mit dem klinischen Bilde verglichen. Bei den klinisch weit vorgeschrittenen Fällen findet man gute Übereinstimmung zwischen dem Grade des Schwundes der Kalziumsalze einerseits und der Schwere der Krankheit andrerseits.

Die beschriebene Methode scheint sich zum Studium einer Anzahl von Problemen der quantitativen Röntgendiagnostik zu eignen.

RÉSUMÉ

Description d'une méthode pour déterminer quantitativement le contenu en sels de calcium des tissus osseux. En photographiant, simultanément, sur le radiogramme un système de référence sous la forme d'une série de marches cunéiformes en aluminium il est possible de calculer l'absorption au niveau des diverses parties de l'os et de l'exprimer en unités du système de référence.

Discussion des différentes causes d'erreur inhérentes à la méthode.

Le procédé est utilisé pour étudier le degré de diminution des sels de calcium chez des malades atteints de polyarthrite chronique. Les chiffres quantitatifs obtenus sont très en regard du tableau clinique. Dans les cas cliniquement avancés on trouve un bon parallélisme entre le degré de diminution des sels de calcium et la sévérité de la maladie.

La méthode décrite se montre appropriée à l'étude de nombre de problème ressortissant au diagnostic radiologique quantitatif.

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MICRORADIOGRAPHY [1]

by

Arne Engström

1. Introduction

As the roentgen rays cannot be refracted in any kind of optical system analogous to that in the light or electron microscopes, enlarged images with roentgen rays cannot be obtained with an optical or electrical lens system.[2] One way to obtain enlarged images by roentgen rays is to make a sharp »shadow» image of the sample which allows a considerable optical magnification. The procedure is called *microradiography* and the small roentgen picture is called a *microradiogram*.

If, however, the microradiographic procedures for obtaining enlarged images were developed in a quantitative direction and the simple and clear laws that govern the absorption of roentgen rays were taken into account such *quantitative microradiography* would be of great value to a number of different research fields. Such methods would be particularly useful in mineralogy, metallurgy, biology and medicine. In biology and medicine a great number of problems dealing with the chemical composition of cells and tissues during different normal and pathological conditions could be attacked.

This paper first describes the different principles for microradiography. A brief review of the literature is also presented and this review is as complete as possible. The methods for quantitative microradiography as developed by the author are then described.

2. The principles for microradiography

There are different techniques for microradiography. Fig. 1 illustrates the possible experimental arrangements. In fig. 1 a, which illustrates

[1] An extended survey after a lecture given to the Swedish Radiological Society, November 26, 1948; submitted for publication, May 9, 1949.

[2] By cylindrical or spherical crystal surfaces a low power magnifying system for roentgen rays can be constructed. Cf. v. Hamos and Engström (1944).

the most common method for microradiography, the roentgen beam passes through the sample, S, which lies in good contact with the fine grained film, F. A diaphragm, L, limits the area of the sample irradiated. After development, an image in the scale 1 : 1 is obtained on the film and that film is subsequently enlarged by an optical system *e. g.* a microscope. The resolving power of the procedure depends on the granularity of the film emulsion and the geometrical arrangements of the roentgen tube, sample and film.

A primary magnification obtained by roentgen rays is shown in fig. 1 b. A point source of roentgen rays is used and the sample, S, and the film, F, are placed at a certain distance from each other. A point

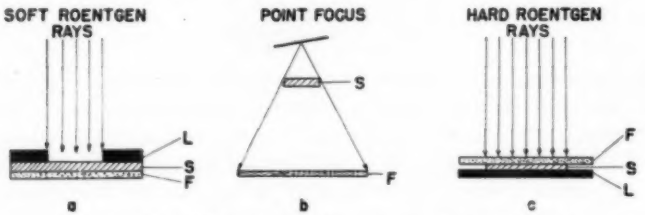

Fig. 1. The different techniques for microradiography. *L* lead plate. *S* sample. *F* photographic film.

source can be obtained by placing a fine pin hole in front of the roentgen tube (SIEVERT 1936) or by focusing the electrons in the roentgen tube to a very fine point on the anode (v. ARDENNE 1940). The latter principle for microradiography is also called »roentgen ray shadow microscopy». See v. ARDENNE (1940) and ZWORYKIN et coll. (1947). The magnification depends on the mutual distances between sample, film and roentgen source.

In fig. 1 c the principle for microradiography with extremely hard roentgen rays is shown. The hard roentgen rays (up to several hundred kilovolts) first pass through the film, F, and hit the sample S. These hard roentgen rays do not blacken the film. The secondary electrons emitted by the sample, however, do blacken the photographic emulsion and produce an image of the sample (TRILLAT 1948, SEEMAN 1949). In order to increase the yield of electrons a lead plate L is placed behind the sample. The method is a kind of electronic micrography or low power electronic microscopy without lenses.

3. Earlier publications on qualitative microradiography

The very first publications on microradiography appeared a few years after Roentgen's discovery of the X-rays. »As early as 1898 HA-

COCK and NEVILLE in England made use of a radiographic procedure in an experiment which was the direct forerunner of the present day microradiographic technique. In an alloy of gold and sodium, due to the high roentgen absorption coefficient of gold as compared with sodium, they were able to bring out quite clearly the dendritic structure of the solidified alloy and to verify that the solidification was accompanied by a variation in chemical composition which was exactly in accordance with the predictions of the phase theory. Unfortunately at that time and for many years thereafter, the available photographic emulsions were not capable of any large degree of magnification. Therefore, the work of HAYCOCK and NEVILLE was done at unit magnification, in other words under the conditions of normal radiography. Little further work was done along these lines for a considerably number of years thereafter.» (Quoted from MADDIGAN 1946.) In 1913 P. GOBY in France published the results from his microradiographic investigations utilizing soft roentgen rays to obtain detailed images of algae etc. on relatively fine grained films.

»Finally, with the introduction of fine grain photographic emulsions capable of suitable magnification, work on the development of the technique was resumed in France. This was confined chiefly to light alloys and in order to obtain a maximum differential absorption between the various alloy components, the use of low voltage, long wavelength radiation was required. In order to avoid excess exposure times, absorption in the specimen was reduced by the use of extremely thin samples and air absorption was minimized by making the exposures within a vacuum. Under these conditions the technique was extremely arduous and unwieldly and indeed it is only recently that advances have been made in the technique which make the method practicable for use in the average metallographic laboratory» (MADDIGAN 1946).

In France the microradiographic technique also was used for the investigation of biological material. 1930 DAUVILLIER published beautiful pictures of microtome sections from tissues with the use of soft roentgen rays. In 1936 LAMARQUE published the first of a long series of papers dealing with microradiography of biological material. LAMARQUE employed a specially constructed roentgen tube which was evacuated continuously and the specimens investigated in high vacuum. The tube voltage was 5 kVs. The published pictures are of very high quality. Some of the investigations were performed in collaboration with the histologist TURCHINI. The latter author has also published a series of papers on microradiography and its use in pathology. Quantitative measurements were not performed and the images obtained did not allow any chemical interpretation.

A paper on microradiography performed according to the principles

shown in fig. 1 a and 1 b was published in 1936 by R. SIEVERT. This author pointed out the possibilities of adjusting the wavelengths used to the absorption edges of the elements in the sample so that the contrast between the elements in the sample should increase and the images allow a chemical interpretation.

Similar attempts have been made by CLARK and coworkers. For the literature see CLARK (1940 p. 180 et seq. and 1944 p. 146 et seq.) and SPROULL (1946 p. 287 et seq.). These authors used the total radiation from roentgen tubes driven with relatively high voltage and fitted with anodes of material with low atomic numbers in order to take advantage of the characteristic K-α radiation. CLARK states that by using such »monochromatic radiation» it is possible to make the different components in an alloy to stand out with different strengths by making exposures with different wavelengths. For similar investigations on biological material reference should be made to DERSHEM (1930) who, however, used the characteristic secondary radiation from an element for his experiments. Beautiful pictures of different alloys are published by CLARK and coworkers and by MADDIGAN (1946). References to the papers dealing with microradiography of alloys are *i. a.* found in CLARK (1940), SPROULL (1946) and in »Handbook of Industrial Radiology» edited by J. A. CROWTHER.

SHERWOOD described in 1946 a specimen chamber which could be evacuated in such way that the sides were pressed together causing extremely good contact between the sample and the film. TRUETA in 1947 published beautiful pictures of sections from kidneys which had been injected with substances giving high roentgen contrast. Finally BOHATURTSHUK (1942, 1944) investigated the distribution of blood vessels in the tissues by means of microradiography. Contrast medium was injected in the vessels and the magnification used was about 50 times. A Bucky roentgen tube was used. The laboratory manufacture of LIPPMANN film was also described.

4. Quantitative microradiography

In the following sections the methods for quantitative microradiography developed by the author will be described. The estimation of the absorption of roentgen rays in a small area of a sample by photometric measurements in the microradiogram makes it possible to determine the mass of a cell structure as well the amount of certain elements in it. The wavelength of the roentgen rays used must be properly selected for each purpose. For determining the mass, continuous (white) roentgen rays are used, but in the case of elementary analysis monochromatic roentgen rays must be used.

In order to obtain a sharp image with maximal resolving power, in ordinary microradiography, the sample and the film must be in extremely good contact with each other. Very fine-grained film emulsions must be used. Fig. 2 shows the geometrical arrangement for the film, sample and roentgen ray source and from the figure it can be seen that the maximal unsharpness, U, for a point on the surface of the sample is:

$$U = \frac{f \cdot a}{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

In this formula, f denotes the size of the focal spot in the roentgen tube; a is the thickness of the sample, which lies in good contact with the film; and b the distance between focus and film. The geometrical unsharpness is small when the focal spot is small, the distance between focus and sample-film long or the distance between sample and film very small. Unfavourable intensity conditions, however, make it impossible to have a high value of b, and the load of the tube makes it impossible to have a small value of f. The most important factor, besides the granularity of the film, is to keep a very small.

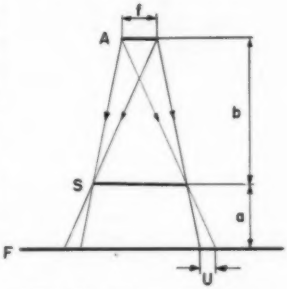

Fig. 2. The geometrical unsharpness.

The properties of the film emulsions are the limiting factors of the resolving power of the method. The following table 1 shows the resolving power for some film emulsions. Resolving power is given in lines /mm and the best emulsion is the LIPPMANN emulsion which resolves more than 1,000 lines/mm, provided that the contrast is good in the sample. A LIPPMANN film can be optically magnified c:a 500 times without disturbance from the silver grains. Electron microscopic investigations have shown that the grains in a LIPPMANN emulsion have a diameter of about 1/25,000 mm. The sensitivity, however, for this film

Tab. I.

The resolving power of some photographic emulsions.

Film emulsion	Resolving power lines/mm
Kodak X-ray film	$\sim$ 10
Agfa Printon film	$\sim$ 50
Ilford High Resolution plate	$\sim$ 100
Eastman Kodak Spectroscopic plate 548—0	500
Eastman Kodak Spectroscopic plate 649	$\geq$ 1,000
Lippmann film	$>$ 1,000

emulsion is very low. For wavelengths used for diagnostic purposes the LIPPMANN emulsion is about 10,000 times less sensitive than ordinary roentgen film *e. g.* LAUEfilm.

Enlarged images of the microradiograms are obtained by ordinary photomicrography. In order to obtain good pictures it is advisable to mount the small roentgen films in canada balsam in the same way as ordinary histological sections are mounted.

5. Determination of the mass of small objects by microradiography with continuous roentgen radiation

The schematic appearance of the continuous (white) roentgen spectrum is shown in fig. 3. The short wavelength limit λ min. is determined by the voltage V across the roentgen tube:

$$\lambda_{min} = \frac{12{,}340}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where λ min. is obtained in Å.U. (1/10,000,000 mm) if V is measured in volts. The maximal intensity in the continuous spectrum lies at 1.5 to 2 times λ_{min}.

Soft roentgen radiation (long wavelengths) must be used for securing good contrast in biological specimens of minute thickness. The suitable wavelengths for obtaining good contrast with a 5 μ thick section of an ordinary tissue and for bone tissue can be seen from fig. 4 where the transmission of the roentgen rays is plotted against wavelength. The

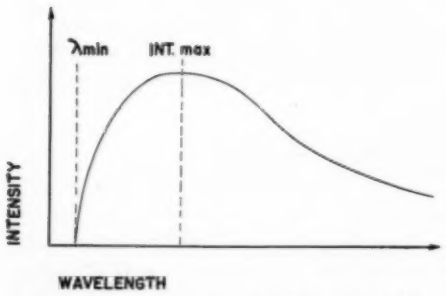

Fig. 3. The intensity distribution in the continuous roentgen spectrum.

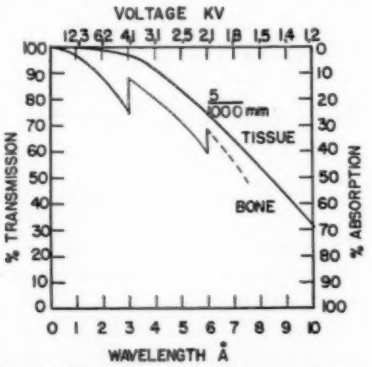

Fig. 4. The absorption of roentgen rays in a 5 μ thick section of an ordinary tissue (upper curve) and bone tissue (lower curve), as a function of the wavelength.

voltage that corresponds to a short wavelength limit indicated by the wavelength scale is printed at the top of the diagram. For a 5 μ section of tissue the suitable voltage lies in the region 500—5,000 volts but for bone tissues higher voltages may be used.

As the successful production of the microradiograms requires extremely soft roentgen rays the whole procedure must take place in high vacuum. A specially built experimental apparatus for very soft roentgen rays has been constructed (see below).

The principle for the method of mass determination is briefly described with reference to fig. 5.

The use of a continuous roentgen spectrum in microradiography makes it possible to determine the mass (weight) of small biological objects. The effects of the absorption jumps of the elements in the tissue can be neglected. The total absorption of the roentgen rays is in ordinary tissues proportional to the total mass of the tissue. In fig. 5, *A* is a metal preparation holder and over the slit a thin collodium foil is laid. This foil serves as a supporting membrane for the sample. The microtome section or a smear of the tissue being examined is laid on one half of that membrane, *B*. The other half of the membrane, *C*, is reserved for an absorption wedge made of thin collodion foils. The roentgen absorption of the foils should be of the same order as that of the sample. The preparation is laid against the photographic emulsion of a LIPPMANN film or any other fine-grained photographic emulsion. Very good contact must be secured. The microradiogram is then produced with long wavelength, continuous, filtered roentgen rays (500—4,000 volts). The voltages chosen depend on the nature of the sample. The roentgen image of the sample and wedge is enlarged 200—500 times by photomicrography. Absorption in single cell structures can be compared with the absorption in the collodion foils and the relative distribution of the amount of dry substance (mass) in the sample can be computed by photometric measurements on the enlarged image. Knowing the chemical composition and the weight per unit area of the foils used for the wedge, the absolute values of weight in the sample can be calculated.

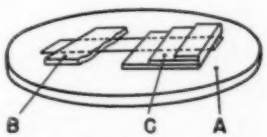

Fig. 5. Mounting of the specimen *B*, and the wedge *C* on the sample holder *A*.

The complete mathematical theory for the determination of mass by microradiography including the effect of high atomic elements will be published by ENGSTRÖM and LINDSTRÖM. The errors will be discussed and proper experimental conditions derived.

The experimental apparatus described by ENGSTRÖM and LINDSTRÖM (1947) can be used but as this apparatus requires rather long exposure

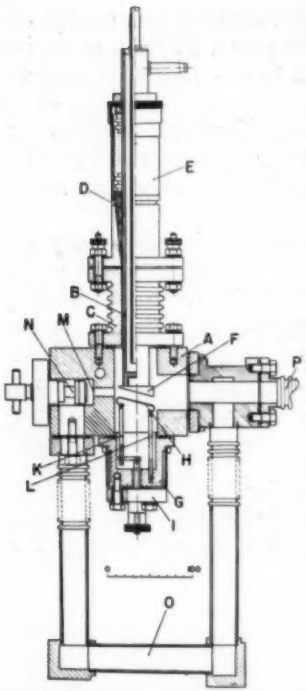

Fig. 6. The roentgen tube used for the determination of the mass of cell structures. *A* brass body of the tube. *B* water cooled anode. *C* porcelain insulator. *D* greased cone. *E* metal bellows. *D* and *E* make it possible to adjust the anode in the high vacuum. *F* target. *G* cathode holder. *H* tungsten filament. *I* electrically isolated connection to *K*. *L* the second connection to the filament. *M* a 9 μ thick aluminium foil. *N* sample holder. *O* vacuum lead to the sample holder *N*. *P* high vacuum lead.

times a new and more powerful roentgen tube has been constructed. A cross section of the roentgen tube, which is water-cooled, is shown in fig. 6, in which, also, the sample holder *N* is shown. An aluminium filter, *M*, 9 μ thick cuts off the light from the cathode and at the same time filters the radiation properly. For explanation of the symbols see the text to the figure. The tube is evacuated by a molecular pump of SIEGBAHN's design backed with an ordinary fore pump. The high voltage is carefully stabilized and the apparatus provided with automatic control of high voltage, emission, timing, vacuum, and water pressure. A photograph of the equipment is shown in fig. 7. The vacuum unit (fore pump and molecular pump) is placed under the table. The roentgen tube stands on the table and to the right in the figure the electronic equipment for stabilization of high voltage etc. is shown. For details regarding the construction see ENGSTRÖM and LINDSTRÖM 1949.

As an example of the use of the method a photograph of a microradiogram of single nerve fibres is shown in fig. 8. The fibres which have a diameter of about 10 μ are prepared according to the method of TASAKI and STÄMPFLI and laid directly on the thin collodion foil on the sample holder. For details the reader is referred to ENGSTRÖM and LÜTHY 1949. From the picture it can be seen that the edges of the fibres have a greater opacity to the roentgen rays than have the centers. The fibres thus have a tubular structure. The absorption of the roentgen rays was measured across these fibers and compared with the absorption in the stepwedge. In fig. 9 the enlarged image of fibres and wedge is shown. The photometer deflections for the different steps on the wedge in the enlarged image were first recorded, fig. 10. The photometer deflections for different parts of the fibers

Fig. 7. Photograph of the tube shown in fig. 6.

Fig. 8. Photomicrograph of a microradiogram of single nerve fibres. 4,000 volts roentgen rays filtered through 9 μ Al. Magnification 100 ×. The black areas are those which absorb roentgen rays.

Fig. 9. Quantitative estimation of the roentgen absorption. To the left the step wedge in the form of a cross and to the right seven single nerve fibres. Magnification 300 ×. The white areas are absorbing roentgen rays.

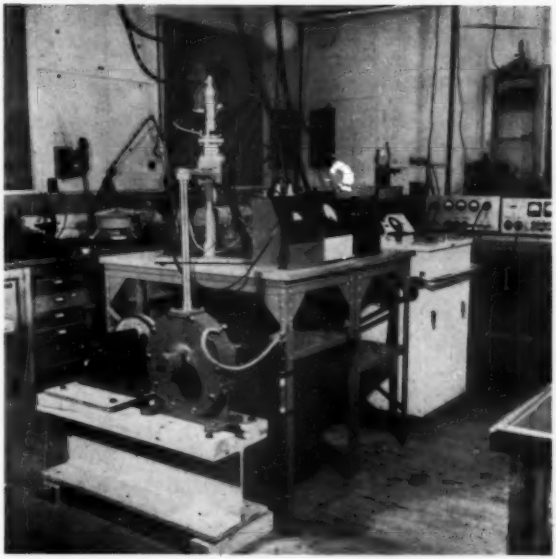

Fig. 7.

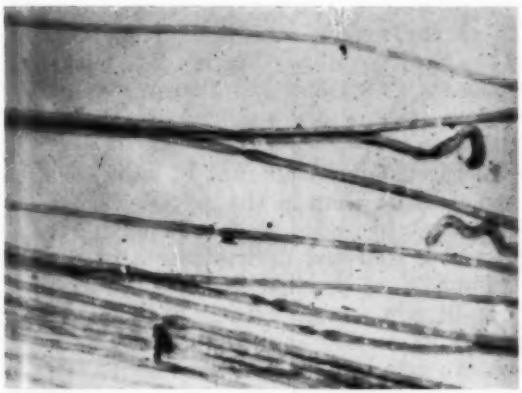

Fig. 8.

Fig. 9.

were then compared with those of the stepwedge. Thus we obtain the mass of different parts of the fibre expressed in units of the wedge. Knowing the composition of the material in the wedge the absolute mass of different parts in the fibers can be calculated. These quantitative

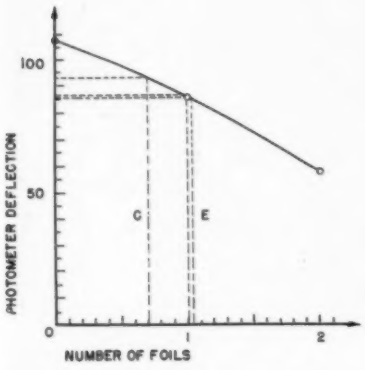

Fig. 10. The photometer deflection for the foils and nerve fibres in fig. 9. E is the edge and C the center of a fibre.

Fig. 11. A photomicrograph of a microradiogram of a few bacteria. 3,000 volts roentgen rays filtered through 9 μ Al. Magnification 1,700 ×.

measurements show that the outer layer (E in fig. 10) of the fibre which histologically corresponds to the myelin sheath has the mass $0.3—0.4 \times 10^{-12}$ g/μ^3. The central part of the fibre (C in fig. 10), which corresponds to the axon, has a mass 5 to 8 times less than the value for the myelin sheath. These values refer to dry weight as the water is taken away during the evacuation.

The fibres have a tubular structure and the amount of substance being considerable less in the axon cylinder than in the myelin sheath. The axoplasm thus has a water content of about 95 %. If the fibres are extracted with lipid solvents and a repeated determination of the mass is performed about 50 % of weight of the myelin sheath is lost. Thus about half of the mass of the myelin sheath consists of lipids. In the axoplasm no loss of weight after extraction could be observed. In fig. 8 the constrictions of RANVIER can also be seen. Experiments to follow changes in the fibres under electrical stimulation are being performed using the roentgen absorption method described above.

In fig. 11 it is shown a microradiogram of a smear preparation of bacteria. The picture shows the good resolving power of the method even at high magnifications.

It can be anticipated that the method of mass determination will be a useful tool when solving certain problems in cytochemistry. By first

determining the mass of a cellular structure in a sample and then, for example extracting the sample or treating it with enzymes, a repeated determination of the mass gives information about the amount of certain substances specifically removed.

By treating the specimen with chemicals which react quantitatively with certain groups in it the increase in mass in comparison with the untreated specimen renders the determination of certain chemical groups possible. ENGSTRÖM and JAKUS (1948) tried to determine the amount of protein (amino groups) in a tissue by treating it with phosphotungstic acid at pH 2, then determining the increased absorption caused by the tungsten.

Microradiography with soft roentgen rays can also be used qualitatively to demonstrate certain substances *e.g.* glycogen which has reacted with iodine, nucleic acids which have reacted with lanthanum ions etc. by the determination of the increased absorption of these added elements.

6. Elementary chemical analysis by microradiography using monochromatic roentgen rays

In the roentgen absorption spectrum of the elements there appear, at wavelengths characteristic for each element, absorption discontinuities, also called absorption edges or jumps. The position in the spectrum of

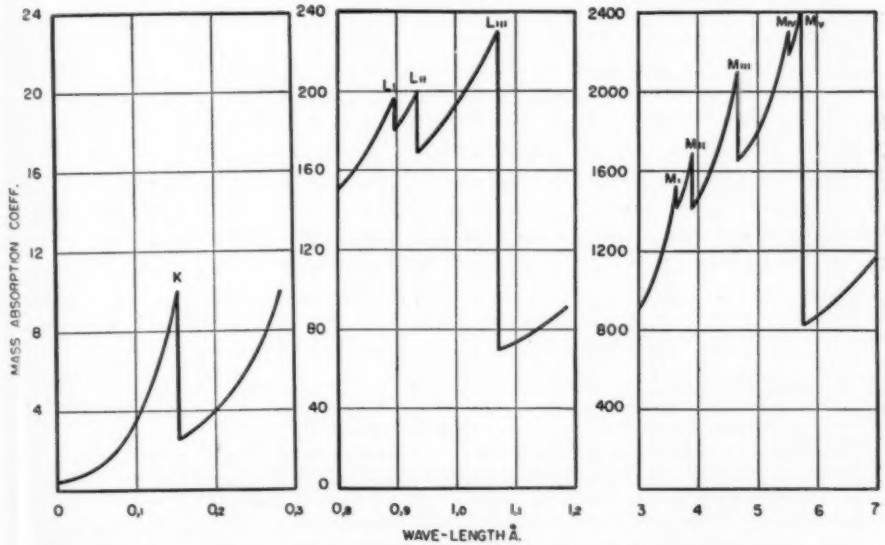

Fig. 12. The roentgen absorption spectrum for platinum.

these edges is an atomic property of the element and is thus not affected of different chemical states of the element. Fig. 12 shows schematically the structure of a roentgen absorption spectrum for an element, in this case for platinum. The absorption edge with the shorter wavelength is the K-edge. At longer wavelengths the L-edges and at still longer wavelengths the M-edges appear. For elements of biological interest, that is the elements with low atomic numbers, it is mainly the K-edge that is used for analysis. In table 2 the wavelengths for the absorption edges of some elements of biological interest are shown (from SIEGBAHN 1931).

Tab. II.

Critical absorption wavelengths, K-edges, for elements of biological interest. The values are given in Ångström units.

Element	*K*-edge	Element	*K*-edge
6 C	43.5	19 K	3.43
7 N	31.1	20 Ca	3.06
8 O	23.5	26 Fe	1.74
15 P	5.77	29 Cu	1.38
16 S	5.01	33 As	1.04
17 Cl	4.38	53 J	0.37

In fig. 13 is shown schematically the absorption edge in the wavelength region for an element being determined in a compound sample. The principle for the analysis is to estimate the absorption of the roentgen rays of two wavelengths lying on either side close to the absorption edge. By those absorption measurements the size of the absorption jump can be estimated and as the size of the jump is proportionate to the amount of the element, this can be calculated. The absorption of the whole specimen can be broken up into one component comprising the element being searched for, X, and one component comprising all other elements in the sample ($q - X$). The mass of the sample thus is q g/cm².

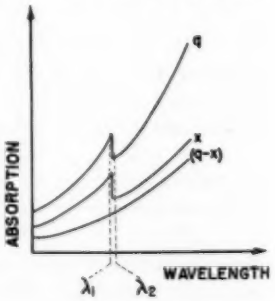

Fig. 13. Schematic representation of the roentgen absorption for a compound sample in the region of the K-absorption edge for a particular element. The absorption of the total mass of substance q can be broken up into two fractions, one comprising the element x, sought for, and one comprising the other element ($q - x$).

In the following calculations index 1 denotes the short wavelength side and index 2 the long wavelength side of the absorption edge. $\frac{\mu}{\varrho}$ indicates the mass absorption coefficient for the element X being determined, and $\frac{\mu'}{\varrho'}$ the mass absorption coefficient for $(q - X)$. I is the intensity of the incident radiation and i the intensity of the transmitted radiation. For the two wavelengths λ_1 and λ_2 the following equations hold good for the calculation of X:

$$\left.\begin{aligned} i_1 &= I_1 \cdot e^{-\left[\frac{\mu_1}{\varrho} \cdot X + \frac{\mu_1'}{\varrho'}(q - X)\right]} \\ i_2 &= I_2 \cdot e^{-\left[\frac{\mu_2}{\varrho} \cdot X + \frac{\mu_2'}{\varrho'}(q - X)\right]} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

If the area being analyzed is Y cm^2, and λ_1 lies relatively close to λ_2, the equation can be transformed to:

$$X = \frac{ln\frac{i_2}{I_2} \cdot \left(\frac{\lambda_1}{\lambda_2}\right)^P - ln\frac{i_1}{I_1}}{\frac{\mu_1}{\varrho} - \frac{\mu_2}{\varrho}\left(\frac{\lambda_1}{\lambda_2}\right)^P} \cdot Y \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

In this equation the exponent p is a function of the product wavelength times atomic number $(Z \cdot \lambda)$ and varies continuously from 3 to 2.3 when $Z \cdot \lambda$ increases from 8 to 800 (JÖNSSON 1928). Biological material consists largely of C, N and O with an average atomic number of 7. For details the reader is referred to ENGSTRÖM (1946).

From equation 4 it can be seen that it is possible also to determine an element in the presence of other elements. Likewise equation 4 can be used to calculate the smallest possible amount of an element determinable. If I_1 is assumed to have the same value as I_2 and λ_1 lies close to λ_2, a 5 % difference between i_1 and i_2 can be assumed to be the smallest detectable difference. Such a calculation is shown in fig. 14 which figure shows the smallest determinable amount as a function of the atomic number. From the figure it is evident that the sensitivity of the method is greater for elements with low atomic numbers than for those with high atomic numbers, a fact which is favourable for the analysis of biological material.

When determining a small amount of a substance by the absorption technique the quotient between the incident and transmitted radiation must be determined with a certain accuracy. When performing a microanalysis the values in fig. 14 must at least be doubled. The smallest determinable amount of an element depends on the accuracy with which the quotient between the incident and transmitted radiation can be determined.

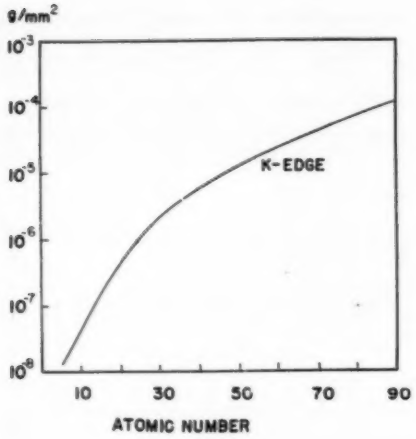

Fig. 14.

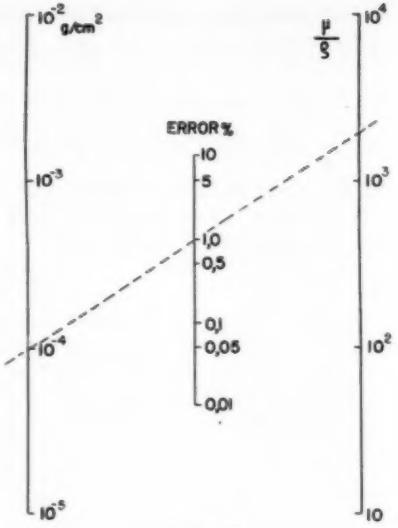

Fig. 15.

Fig. 14. The smallest determinable amount of an element as a function of the atomic number. The curve refers to measurements at the K-absorption edge.

Fig. 15. A nomogram showing the allowed error in the determination of the quotient $\frac{I}{i}$ (the central line) when different amounts of a substance (the line to the left) is to be determined. The line to the right represents the mass absorption coefficient. The dotted line indicates the allowed error in $\frac{I}{i}$ when 10^{-4} g/cm² of a substance with the mass absorption coefficient of about 2,000 is to be estimated with an error of 5 %. Cf. the text.

For one substance X at a given wavelength the following equation is valid:

$$i = I \cdot e^{-\frac{\mu}{\varrho} \cdot X} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

If the allowed error in X (the amount of the substance being determined) is p %, the following holds good:

$$i_E = I_E \cdot e^{-\left[\frac{\mu}{\varrho} \cdot \left(X \pm \frac{p}{100} \cdot X\right)\right]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

From the two equations we get:

$$\frac{I_E}{i_E} : \frac{I}{i} = e^{\mp \frac{\mu}{\varrho} \cdot X \cdot \frac{p}{100}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7$$

The error p % in X corresponds to an error C % in the quotient between the incident and transmitted radiation, thus:

$$C = \frac{\frac{I_E}{i_E} - \frac{I}{i}}{\frac{I}{i}} \cdot 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Combining the equations we obtain:

$$C = 100 \left(e^{\mp \frac{\mu}{\varrho} \cdot X \cdot \frac{P}{100}} - 1 \right)$$

A nomographic representation of the error c when p is — 5 % is presented in fig. 15, from which figure it can be seen that when determining a substance with a mass absorption coefficient of 2,000 and present in an amount of 10^{-4} g/cm² the allowed error in $\frac{I}{i}$ is 1 %. A complete mathematical and statistical treatment of the different errors of the methods described above for determination of mass and the amount of elements will shortly be published by LINDSTRÖM elsewhere.

The summary discussion presented above shows, however, that there are possibilities for determining several elements in a biological

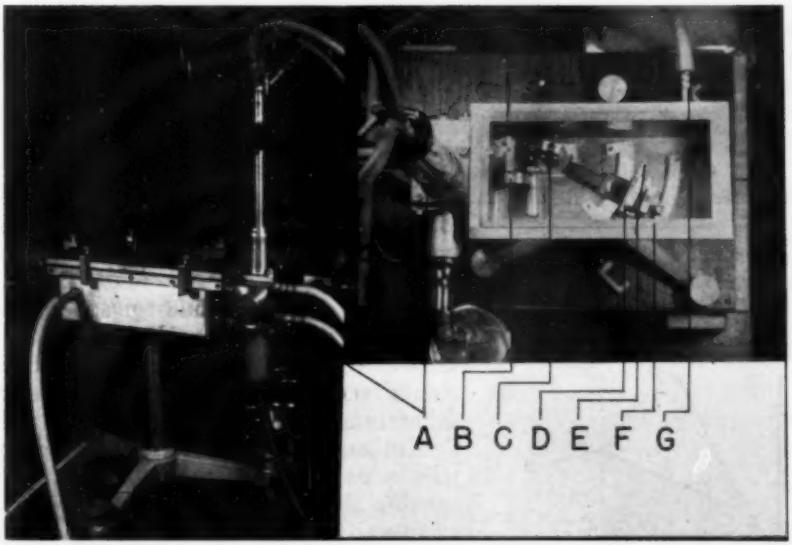

Fig. 16. Photograph of the vacuum spectrograph used for quantitative analysis of elements.

A roentgen tube. *B* adjustible slit. *C* crystal. *D* specimen holder. *E* micrometer screw for adjusting the specimen holder. *F* rubber gasket. *G* side tube for evacuation.

section whose thickness corresponds to that of a single cell layer. For cytochemical analysis it is, however, also necessary to analyze a very small area. This is achieved by taking microradiograms with monochromatic roentgen rays of properly selected wavelengths. In these microradiograms the absorption of the roentgen rays is determined in the same way as is described in section 5. For a point in the sample the absorption of roentgen rays of the wavelengths chosen can be calculated from photometric measurements in the microradiograms and by inserting the values in equation 4 the element being searched for is obtained. The microradiogram also allows the cytological localization of the point being analysed.

An example of the experimental apparatus is shown in fig. 16 and is the one published by ENGSTRÖM in 1946. In the roentgen tube *A* roentgen rays of desired wavelengths can be primarily or secondary excited. The emission lines from the elements, usually the Kα and Lα lines are used. The lines are selected according to the element being analysed. The rays leaving the tube consist of white and line radiation. After passing the slit *B* the roentgen rays strike the crystal *C* at the proper BRAGG angle. The monochromatic roentgen ray beam leaving the crystal *C* then enters the preparation holder *D*, which can be adjusted by the micrometer screw *E*, so that two or more images can be taken on the same film. The spectrograph is evacuated through the tube *H*. The preparation is mounted in the same way as for determination of its mass.

The apparatus described has a relatively small output of monochromatic roentgen rays and therefore the exposure times are very long. A new monochromator with high luminosity which utilizes a curved or spherical crystal is being constructed.

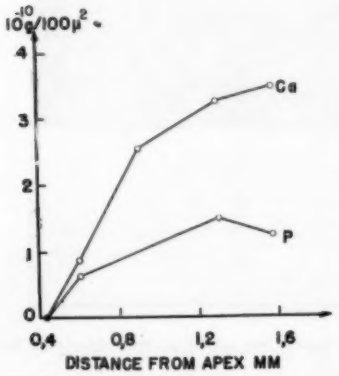

Fig. 17. Determination of calcium and phosphorus in dentine cells in a tooth from a guinea pig.

In fig. 17 the results of some determinations of calcium and phosphorus are shown. The incorporation of these elements was followed during growth and differentiation processes in dentine cells. Continuously growing teeth from guinea pigs were used. For the determination of calcium the Sc and Ca Kα lines with the wavelengths 3.03 and 3.35 Å respectively were used. For the phosphorus determinations P and S Kα lines (6.14 and 5.36 Å resp.) were used.

Another example of the use of the technique described is the determination

Fig. 18. Photomicrograph of a microradiogram of a section of skin. 3,000 volts roentgen rays. Magnification 70 ×.

of sulfur in different layers of the skin. Fig. 18 is a microradiogram of a section of skin, made with polychromatic radiation: 3,000 volts roentgen rays filtered through 9 μ Al. The structures of the skin appear clearly. In a section of skin the amount of sulphur can be determined by taking two microradiograms with monochromatic roentgen rays on either side of the K-absorption edge for sulphur. S and P Kα radiation is suitable. Fig. 19 shows the result of such a determination of sulfur in skin, published in 1947 by ENGSTRÖM and LINDSTRÖM. It is to be noted that the stratum corneum has a

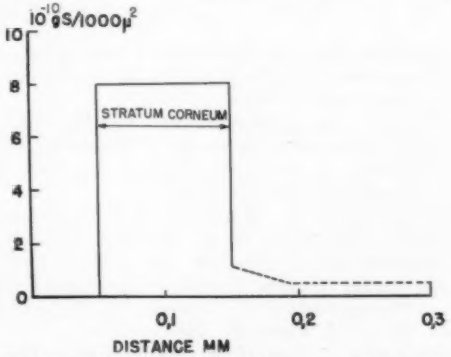

Fig. 19. Determination of the amount of sulfur in different parts of the skin epithelium. (From ENGSTRÖM and LINDSTRÖM 197.)

high content of sulfur which decreases towards the inner layers of the epithelium. The analytical results can be correlated with the degree of growth and differentiation of the cells in the skin epithelium.

SUMMARY

The paper describes qualitative and quantitative microradiography. The use of continuous roentgen rays makes it possible to determine accurately the mass of cellular structures with diameters as small as 1 μ. The analytical procedure is discussed in detail. The production of microradiograms with monochromatic roentgen rays of certain wavelengths permits an analysis for certain elements in the sample. Applications and possibilities of these methods are discussed.

ZUSAMMENFASSUNG

Die Arbeit beschreibt qualitative und quantitative Mikroröntgenaufnahme. Verwendung kontinuierlicher Röntgenstrahlung ermöglicht eine exakte Bestimmung der Masse von Zellenstrukturen mit nur 1 μ Durchmesser. Das analytische Verfahren wird eingehend erörtert. Die Aufnahme von Mikroröntgenbildern mit monochromatischen Röntgenstrahlen von gewisser Wellenlänge ermöglicht die Analyse gewisser Elemente in der Probe. Verwendung und Möglichkeiten dieser Methoden werden besprochen.

RÉSUMÉ

Le travail décrit la micro-radiographie qualitative et quantitative. L'emploi de Rayons Roentgen continus permet de déterminer exactement le volume de structures cellulaires dont le diamètre n'excède pas 1 μ. Le procédé analytique est décrit en détail. La prise de micro-radiogrammes avec des Rayons X monochromatiqeus de certaines longueurs d'onde permet l'analyse de certains éléments de la pièce examinée. Discussion des applications et des possibilités de ces méthodes.

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FROM THE ROENTGEN DEPARTMENT OF KARLSKOGA HOSPITAL, SWEDEN.

HEREDITARY, MULTIPLE, DIAPHYSEAL SCLEROSIS[1]

by

S. Ribbing, M. D.

As opposed to the types of osteosclerosis associated with infections, fractures, diseases of the blood, or abnormal stress, there is a group of sclerosing osseous lesions, the aetiology of which is less clearly understood. This group comprises marble-bone disease, melorheostosis, osteopoecilia, the spotted epiphyses, and — most rare of all, judging by the literature — Engelmann's disease. To a certain degree similar to the latter condition are the cases of multiple, diaphyseal sclerosis observed by me in four siblings. On the other hand, there are certain differences, *inter alia* the familial occurrence suggesting a hereditary disturbance. Hereditary lesions of this type seem to have previously been reported but once. I propose here to give first a survey of the cases on record, with which in my opinion my cases are most closely comparable.

Literary Survey

In 1922, CAMURATI (Bologna) described a rare type of »*symmetrical hereditary osteitis*» involving the lower extremities. The patients examined were a boy aged 7 and his father. A history of the same condition had been disclosed concerning a cousin of the boy's, one sibling and two cousins of the father's, the paternal grandfather of the boy and the grandfather's two siblings and father. Both subjects examined stated to have had pain in each lower extremity »since birth». Fusiform swellings were felt on palpation of the legs below the knee. The boy's radiograms revealed thickening and cortical sclerosis in the lower portion of the femoral diaphyses as well as upper parts of the tibial and fibular diaphyses. The outlines of the bones were smooth. Other parts of the skeleton were apparently not examined. The father presented very considerable, grotesque swellings and sclerosis within the corresponding areas; in his case the outlines of the bones were blurred and the medullary cavity seemed to be obliterated. The Wassermann test was negative in both the father and son.

[1] Submitted for publication May 2, 1949.

ENGELMANN, of Professor Kienböck's Radiological Department in Vienna, in 1929 recorded a case of *osteopathia hyperostotica (sclerotisans) multiplex infantilis*. The case related to a boy of 8 years and 2 months of age, without a familial history of skeletal disease (his relations had not been examined, however). Physical and psychic development seems to have been somewhat retarded in the patient as compared with the average for his age. From the age of 4 onwards he had had trouble in walking and a certain type of pain in the extremities, particularly towards the feet. Roentgenograms disclosed the fact that the diaphyses of all the long bones were the sites of hyperostosis (thickening) and sclerosis encircling the entire cross-section of the long bone. In addition, the bones were somewhat elongated and slightly curved. Fractures had not occurred. The skull showed sclerosis and hyperostosis within the anterior and central cranial fossae. The remaining bones were normal. The lesions were symmetrical. The terminations of the long bones (epi- and metaphyses) were normal. The haematological findings were mild anaemia and a relative increase in lymphocytes, monocytes, and eosinophils. Wassermann test, negative. The spleen was somewhat enlarged.

In 1932, FRITSCH of Bielsko in Poland published a case of generalized osteosclerosis in a woman born in 1903. There was no established familial history, but the relations were apparently not examined. From the age of 14 onwards, the patient had had periods of pain in the right leg below the knee. She was examined in 1923, the radiogram showing increased bulk of the cortical bone and narrow medullary cavity in the right tibia. The patient was slightly anaemic; Wassermann test, negative. In 1924 the pain recurred after having subsided for some time. The X-ray findings were as before: slight diffuse thickening of the bone, marked increase in radiodensity owing to bulkiness of the cortical portion, and obstruction of the marrow cavity. The patient was given roentgen treatment and sodium iodide. Subsequently the pain occurred somewhat less frequently. During the years, 1924—27, condition unchanged, at times pain. In May 1927, pain also in the left leg. Both tibiae presented slight, diffuse thickening on palpation, the skiagrams then showing bilateral lesions. The change in the right leg had somewhat extended in an upward direction; on the left side the site involved was small, *i. e.* only 10 centimetres of the tibial diaphysis, but another sclerotic focus of hazelnut size was noted in the upper tibial metaphysis. In 1931 the patient complained of pain even in the thighs and upper arms, especially the left one, and at that time anaemia was demonstrated, viz. 59 % haemoglobin and 4,000,000 reds per cubic millimetre. Sedimentation rate, 6 mm. Wassermann test, negative. Skiagrams taken in 1932 also showed femoral lesions in appearance equalling those observed in the tibiae. However, in the femora the thickening of the cortical bone was not uniform in degree round the entire circumference of

the thigh-bones, being most conspicuous in the medial parts. In both humeri identical lesions were present. The tibiae did not display any evidence of the process having proceeded since 1927. On examination in 1932, also the basal metabolism was found to be one-third above normal, and a certain restriction was noted of the visual fields. Within the skull minor sclerotic lesions were observed in the anterior and central cranial fossae, as well as slight expansion of the sella turcica with central calcification in the latter. Patho-anatomical examinations were apparently not performed in any of the cases referred to in the foregoing.

In 1948, H. R. SEAR published still another case of *Engelmann's disease* observed in Sidney, South Africa. The case related to a boy aged 10, who had had trouble in walking from the age of 3 onwards. The findings on physical examination were practically normal. Haematology, normal. Wassermann test, negative. The skiagrams disclosed a picture tallying with that observed in Engelmann's case, with an extensive degree of very dense osteosclerosis involving the long bones, mainly in the central parts of the shafts, and especially pronounced in the clavicles, bones of the fore-arms, femora and tibiae. There was also dense osteosclerosis and thickening of the base of the skull, extending into the frontal bone, and of parts of the pelvic bones. Sclerosis was present in most of the long bones, and the osteosclerotic bones showed cylindrical expansion of the central parts, due to great cortical thickening. The changes in the humeri were only slight. As in Engelmann's case the ends of the diaphyses and the epiphyses were not involved. A biopsy was carried out: a number of very small fragments, which were resistant to decalcification and still contained an abundance of calcium in the centre after decalcification for a period which is normally successful in entirely removing such material. Due to the nature of the specimen the bone could not be examined in layers. Nothing abnormal in the structure of the bone was seen in the tiny fragments. The results of various laboratory tests were negative.

NAUHAUSER *et al.* of Boston, Mass. U. S. A. recorded four cases of *progressive diaphyseal dysplasia* characterized by progressive skeletal changes, wasting, and anomalous neuro-muscular signs. Their patients when first examined were 4—6 years old, and were followed up for a period of up to 7 years. No statements were made as to consanguinity between the cases observed, nor were similar cases mentioned in the patients' families. All the long bones were involved in every one of the cases, in three instances also the clavicles, and in one the base of the skull. The X-ray changes consisted of symmetrical distribution of fusiform enlargement of the diaphyses, thickening of the cortex by endosteal and periosteal accretion of mottled new bone without trabecular pattern, progression of the lesion along the long axis of the bone in proximal and distal directions, elongation of the extremities relative to the size

of the child, soft-tissue changes similar to those of underdevelopment of muscles and malnutrition. The epiphyses and metaphyses were normal. Biopsies were performed in two of the cases. Of particular interest is the fact that biopsy specimens were taken from the same case at six-year intervals. At the early stage were demonstrated a markedly thickened bony cortex and some thickening of the periosteum. Microscopically there was an increase in the fibrous component of the periosteum and marked osteoblastic as well as osteoclastic activity. The haversian systems were well formed but the canals often appeared larger than usual and sometimes lined at the periphery by osteoclasts. During later stages, it was loss of cortical compact bone, of which only a very thin subperiosteal layer remained, on which thickening of the periosteum was again evident grossly. The cortex presented a pebbly surface. Normal compact bone was absent, and at its place there was a lacy cancellous bone whose trabeculae were thin and showed increased osteoplastic and osteoclastic activity in different areas. The marrow consisted in the main of a loose mesenchymal type of fibrous tissue with collections of mononuclear cells and haematopoietic cells in small numbers.

Before proceeding to discuss my own cases, I propose to quote an observation made by FEDDEMA in Eindhoven (Holland). His cases are unpublished, but when I had presented my cases at the Meeting of the Northern Association for Medical Radiology held at Oslo in June, 1948, I received a communication from Dr. Feddema. I expect that he will himself publish the cases. A nurse complained of pain in the legs, the radiograms showing slight fusiform thickening, pronounced sclerosis, and narrowing of the medullary cavity within approximately the central portions of both tibiae. The entire skeleton was otherwise normal, the clinical examination revealing no abnormality other than suspected gall-stones. Subsequently Dr. Feddema on my request very kindly informed me of the result of his family investigation carried out with respect to this case. The cases included three sisters and one brother. Only one sister complained of aching pain in the legs. The others were symptom-free and never visited a doctor. The parents were dead and could not be examined. Only one sister was married and had two children, which could not be induced to present themselves for examination. The sister who complained of pain in both legs was 47 years old, and her skiagrams showed distinct changes in both legs. The second was 56 years old and only showed similar alterations in the left and, to a much lesser degree, in the right tibia. The third was 53 years old and showed islands of endosteal proliferation especially in the right tibia. The brother who was 51 years old showed questionable minor changes in the periosteal outline of the tibia.

Report of Cases

Among the roentgenograms to be discussed in the following, there are several that date from investigations carried out before my attention was focussed upon this condition. I am greatly indebted to the senior radiologists of the Roentgen Departments of Örebro Hospital and of Karolinska Sjukhuset in Stockholm respectively for their kindness in lending me the roentgenograms in question and permitting their publication. The same applies to those physicians of Karlskoga Hospital, who prior to my appointment as radiologist did the roentgen work at that hospital.

The first case of multiple, diaphyseal sclerosis observed by me related to the youngest sister among the members of the investigated family. The data concerning this patient will be given last in this report. I saw her for the first time on 13/1/1948, my interest being aroused by her apparently quite obscure osseous changes. She was born in 1928 and had been observed at Karlskoga Hospital since May, 1946. The examinations had been carried out by surgeons working in the hospital. The record dating from the end of 1946, when the patient was hospitalized for observation, contains a statement to the effect that the patient has five siblings, all of whom are healthy, and that she is unaware of any bone diseases whatsoever among her relations.

When dealing with uncommon or puzzling osseous conditions, according to my previous experience a complete family investigation may prove valuable even in those cases where no information as to similar symptoms among other members of the family can be obtained from the patient. In many instances such family investigations will certainly fail to yield evidence, but sometimes, *e. g.* with the case in hand, the result may be gratifying.

The family S.: (1) The father, born 24/8/1877, died in 1945 (he was cremated). He was treated as an in-patient at both the Karlskoga and Örebro Hospitals. He complained of pain in the legs interpreted as due partly to injuries and partly to varicose veins and thromboses, for which he was treated repeatedly. Judging by the results of my inquiries at both hospitals, roentgen examination of the skeleton does not seem to have been performed.

(2) The mother, born 24/11/1885, was examined by me on 19/11/1948. She presented no symptoms of osseous disease, and roentgen examination of her skeleton was entirely negative.

As yet I have not made a genealogical investigation pertaining to the progenitors of these two persons; however, since they derive from different parts of Sweden, consanguinity of them appears hardly probable.

(3) Evert, S., born 7/5/1905, has never had pain in the legs or other pathological symptoms to be referred to the organs of locomotion. The findings on roentgen examination of all the long bones were perfectly normal. The same applies to his three children, born in 1934, 1943, and 1945 respectively.

(4) Margit J. née S., born 8/11/1906, has never had pain in the legs or other symptoms pertaining to the locomotor system. Roentgen examination of the entire skeleton yielded quite normal findings, as was the case with her three children, born in 1934, 1940, and 1945 respectively.

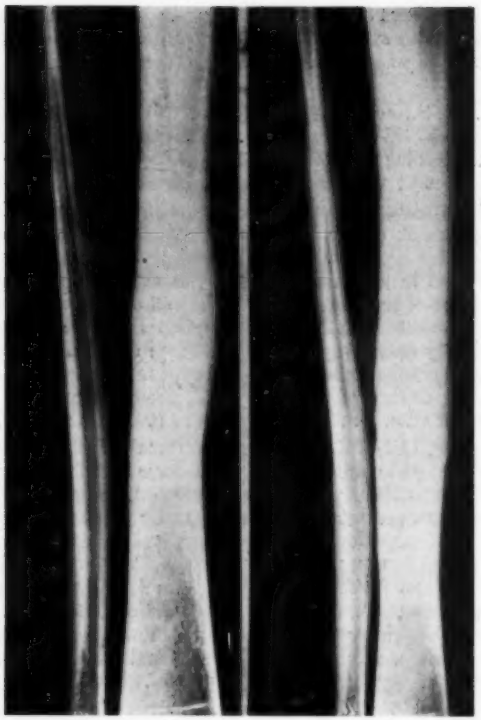
(5) Dagmar A. née S., born 17/4/1914: Since 1940 pain in both legs above the ankle, commencing on the right side; a year later even on the left side. Improvement on right side since 1944. In the left leg still some slight discomfort. Treated *inter alia* with roentgen-rays in moderate doses at Örebro Hospital during the years 1941—1943.

In 1941 repeated roentgenograms were taken of the right leg below the knee. These disclose fusiform expansion of the bone and pronounced sclerosis, with compact bone, thickening of the cortical layer, and obstruction of the medullary cavity, within an area 7 cm. long and situated in the middle of the tibia shaft. The change seems to involve the entire circumference of the bone. Towards the end of 1942 the process has apparently somewhat extended, at that time affecting approximately 10 cm. of the length of the tibia shaft. Then a previously only suggested irregularity in the outline of the bone was also conspicuous. On that occasion roentgenograms were made also of the left leg below the knee. A corresponding change of the same type, though somewhat less extensive, was there noted. On examination a month later, viz. in 1943, the findings were the same.

On my examination, 19/1/1948 (*i. e.* $6^1/_2$ years after the first observation of the lesions), within both tibial diaphyses an area of about 20 cm. was noted of very marked eburnation. The medullary cavity was there practically obliterated, the outline of the bone slightly expanded as before, the compact substance markedly thickened and condensed. There was just a suggestion of cancellous structure. Epiphyses and metaphyses, N.A.D. When the remainder of the skeleton was examined, similar sclerosing lesions with thickening of the compact substance and fusiform expansion were found in the left femur shaft, viz. within an area of more than 20 cm., and the distal portion of the right radius shaft within an area 5 cm. long. The left humerus and right femur showed foci of minor, uncharacteristic and just traceable sclerosis, presumably within normal limits. The other skeletal parts examined did not present any deviations from normal.

The patient has a child that does not show any signs of abnormal changes; roentgenograms of the crural bones fail to disclose changes deviating from normal.

(6) Sven S., born 12/4/1918. Having been healthy before, in the autumn of 1941 the patient was hospitalized for a week at the Karolinska Sjukhuset in Stockholm. A year previously he had been struck in the left leg below the knee by a heavy lump of iron. The blow hit the medial aspect near the anterior ridge. After a week the discomfort resulting from this injury had subsided. Two to three months later the patient observed a firm, elongated swelling in the place hit by the blow. At that time he had neither pain nor other discomfort, but about half a year later he experienced pain, which he describes as somewhat resembling toothache, in the leg below the knee. The pain was continuous, but not very sharp. Occasionally it was apt to radiate into the foot. The record of the Karolinska Sjukhuset gives the following data: Slightly below the m dle of the tibial crest there is a swelling measuring 3—4 by 10 cm., which is firm to the touch, non-tender, not adherent to the superjacent skin, attached to the tibia, into which it fuses without appreciable demarcation. General condition, N.A.D. Wassermann test, negative. On roentgen examination of the left leg the central portion of the left tibial diaphysis showed moderate fusiform expansion; in addition, there was considerable thickening of the cortical layer, obstruction of the medullary cavity, and sclerosis of the cancellous bone. Metaphyses and epiphyses were normal. Angiography, which did not disclose vascular abnormality in the left leg, was also performed. The condition was interpreted as post-traumatic periostitis.



a. b.

Fig. 1. a. b. Case 5. Dagmar A. Right tibia. a. 3. 9. 41. b. 19. 1. 48.

On repeated examination 28/5/1948 the sclerosed lesion showed some extension in an upward direction. The tibia shaft within the area previously affected has not further increased in bulk, but to some extent this has happened on a higher level. The cortical bone has become thicker and more dense, and within some portions of the affected region every trace of a medullary cavity has disappeared. The right leg below the knee does not show any changes of this type, being entirely normal, as is the rest of the skeleton including the skull.

This man has three children, but I was incapable of persuading them to report themselves for examination at the hospital.

(7) Gunnel M., née S., born 23/5/1923. This member of the family has never experienced any discomfort in the extremities, nor has she ever been ill apart from quite transient disorders. Clinically she does not present swelling of the legs below the knee or any other symptoms appreciable on physical examination. Roentgen examination of all the long bones discloses in both femora a cylindrical, somewhat bulky expansion of the upper two-thirds of the diaphyses. There is definite thickening of the compact substance, obstruction of the medullary cavity, and sclerosis of the entire region. The change is some-

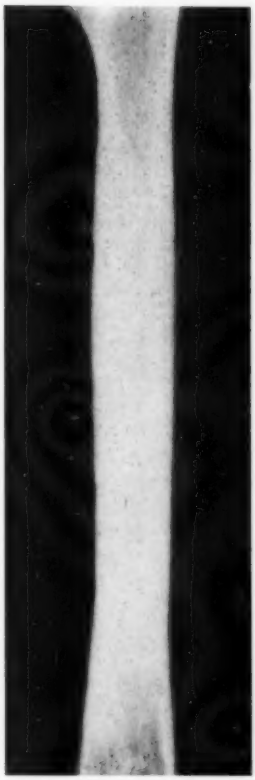


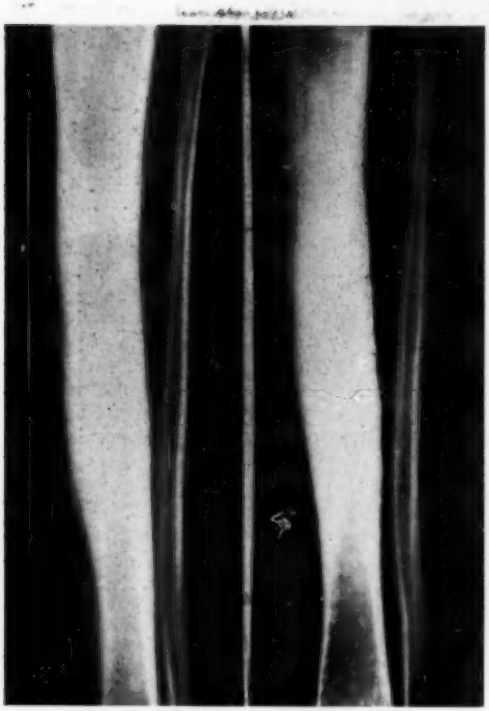
Fig. 2. Case 5. Dagmar A. Left femur 19. 1. 48.

Fig. 3. Case 5. Dagmar A. Right forearm.

what more marked on the right side, where there also is a certain broadening of the compact bone within the lower third of the diaphysis, especially in its posterior and medial aspects, in the form of irregular endosteal ossification. Femoral metaphyses and epiphyses without visible changes. In the left leg below the knee a quite inconsiderable thickening, increased osseous density, and possibly slight broadening of the compact bone are noted within the uppermost portion of the diaphysis. The changes are so slight, however, that without knowledge of the other lesions in the patient and her siblings they would probably have escaped observation.

This patient has a child, born in 1944, which has not experienced any discomfort as regards the extremities. The roentgenogram of the crural bones does not show visible changes.

(8) Astrid S., born 10/3/1928. The patient, who previously always had been healthy, for a period towards the end of 1945 suffered from a dull pain in the forehead. She saw



a. b.

Fig. 4. a. b. Case 6. Sven S. Left tibia. a. 29. 10. 41. b. 28. 5. 48.

Fig. 5. Case 7. Gunnel M. Left femur 21. 5. 48.

a physician, and at that time probably had a certain degree of anaemia. She was given a prescription containing *inter alia* iron, and her condition improved. Towards the end of 1946 the headache recurred for a period. In the spring of 1949 the patient observed a spot on the right leg below the knee, which was painful when she was sitting down. The pain increased, and she also noticed that the leg began to swell on the place affected. Both pain and swelling subsequently increased by degrees, the patient during the later part of the year, 1946, observing that even the left leg below the knee began to be painful, at first without increase in bulk. She reported herself at Karlskoga Hospital, was examined, and roentgenograms were taken. On that occasion she stated that the pain was keener at night, being boring in nature (somewhat resembling toothache). The patient was admitted to hospital and there observed for 12 days towards the end of December, 1946. There was a diffuse fusiform thickening, which was tender on pressure, on the anterior aspect of the upper half of the right tibia. The skin superjacent to the swelling was normal, there being no adhesions between the skin and the subjacent periosteum. In the left leg below the

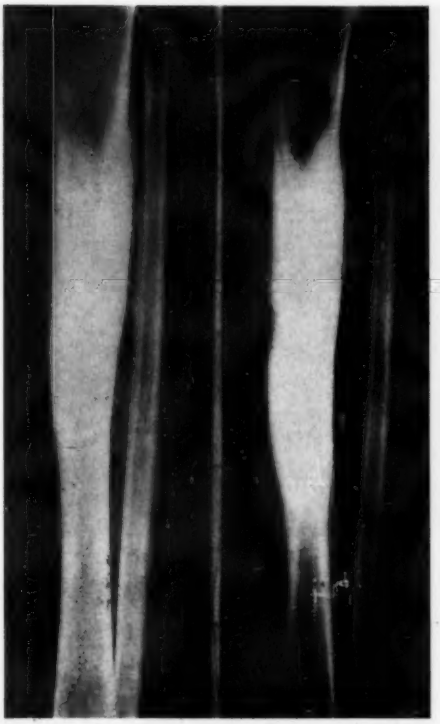


Fig. 6. a. b. Case 8. Astrid S. Right tibia. a. 7. 5. 46. b. 13. 1. 48.

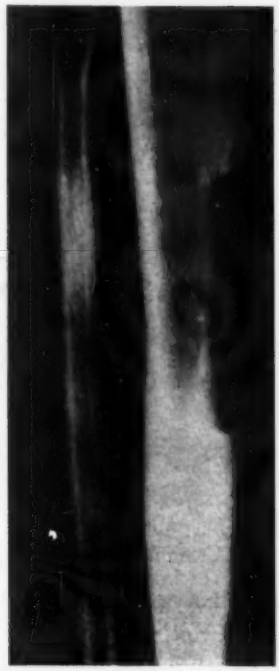


Fig. 7. Case 8. Astrid S. 24. 4. 48. Left tibia (defect from biopsy).

knee there was just a suggestion of a commencing swelling in the corresponding area. Otherwise there was no abnormality on general examination. The haematological findings were, Hb. 89 %, reds 4,780,000 per mm.^{3}, whites 7,200 per mm.^{3} Differential count, N.A.D. S.R. 6 mm. per 1 hour. Wassermann test negative.

Early in January, 1947, the patient was re-admitted to hospital. She had been advised to take potassium iodide, but this entailed a skin eruption, for which reason the drug had to be abandoned. On 10/1/1947 a biopsy specimen was taken from the right tibia, a small piece of bone being removed from the markedly sclerosed diaphysis. The patho-anatomical examination disclosed osteosclerosis. The cortical as well as the cancellous bone showed sclerosing changes. In the cortical layer the Haversian canals were obstructed, in the cancellous bone there was thickening of the trabeculae.

In January, 1948, a fresh roentgen examination, showing progression on the left side, was carried out. The haematological findings were then, Hb. 85 %, reds 4,000,000, whites 7,200 per mm.^{3} S.R. 2 mm. per 1 hour. The patient was given roentgen treatment in fairly small doses.

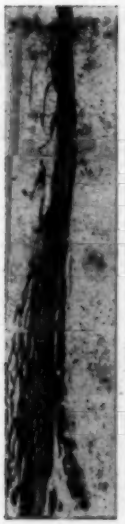


Fig. 8.

Fig. 9.

Fig. 8. Combination photograph of a longitudinal section through the entire biopsy specimen.

Fig. 9. Low-power photomicrograph. Marginal zone of the eburneous layer.

On my request the patient was re-admitted on 26/2/1948. During the first part of 1947 her condition had somewhat improved, but she became worse during the later half of that year. She had then more pain in her left leg, but possibly somewhat less in the right leg. On 27/2/1948 a fresh biopsy specimen was taken from the left leg, a bar measuring 7 by (approximately) 1 cm. being chiselled off the anterior tibial crest at the transition between normal and sclerotic bone near the upper margin of the lesion visible in the skiagram.

Roentgen examinations: The oldest roentgenograms here available date from 7/5/1946. In these the right tibia displays fusiform thickening within a 10 to 12 cm. long portion of the diaphysis. In the area affected there is thickening of the cortical bone with considerable obstruction of the medullary cavity. Within the bulky area the cortical bone is entirely eburneous. The patient was re-examined in May, August, and November, 1946, the pelvis and hip joints being examined, no appreciable changes, as well as the skull (one parietal exposure), also without established pathological changes. From 11/12/46 dates a radiogram of the left leg below the knee, where one finds a suggestion of sclerosis and compact thickening in the middle of the tibial diaphysis, with slight narrowing of the medullary cavity within an area about 4 cm. long. Also in the upper fibular diaphysis of the same leg, there is a suggestion of sclerosis involving an area of about 2 cm. in length. On the same occasion the left knee joint and right femur were examined, without visible changes.

On 12/12/46 roentgenograms were taken of the upper arms and fore-arms; no visible changes.

Fig. 10.

Fig. 11.

Fig. 10. Normal internal cortical layer of the bone.
Fig. 11. Maximum bulk of the layer of new bone. (Enlargement, the same as in Fig. 10.)

12/2/47. The process in the right tibia is found to have extended. Now about 15 cm. of the length of the diaphysis is involved. In the anterior part a depression, resulting from the biopsy, is noted in the bone. Also on the left side the process shows some slight progression, viz. the tibial diaphysis is still more thickened, and the medullary cavity more obstructed. At the same time roentgenograms were taken of the femora, which still failed to display any appreciable changes.

On 13/1/48 the process on the right side appears principally unchanged. The operative osseous defect is partly filled up. On the left side, however, the process has further somewhat increased. At present it involves about 8 cm. of the central portion of the diaphysis, and within this region there is now more conspicuous fusiform expansion, the medullary cavity being obstructed to a higher degree. The little lesion within the upper part of the fibular diaphysis is unchanged. Further were examined the femora, brachial bones, hip joints, and pelvis, which did not show appreciable changes.

24/4/48. The process in the left leg below the knee principally as before. In addition there is in the tibia an operative defect about 7 cm. in length, the lower part of which extends into the area involved; the upper part, however, seems to be situated within normal bone. Supplementary examinations were made of the thoracic and lumbar vertebrae, hands, and wrists, without appreciable pathological findings.

As regards the skull, a parietal exposure was made on 12/12/1946, and a more complete examination in December, 1948. Definitely established changes are not visible in the roentgenograms taken on those occasions. Possibly a very slight increase might be suspected in the osseous density and bulk of the bone forming the base of the anterior

cranial fossa. The roentgenograms were examined by our most experienced specialists in cranial radiology at the Roentgen Department of Serafimerlasarettet, but even these were doubtful as to whether there was actual sclerosis in the base of the cranial fossa.

Patho-anatomical diagnosis (FG 1412/48, Prof. GELLERSTEDT): Biopsy specimen 27/2/48. Periosteal tissue, N.A.D. Longitudinal sections were made of the bone, approximately perpendicular to the centre of the medullary cavity. The pathological process consists in cortical osteosclerosis, to all appearances principally affecting the superficial (subperiosteal) portion of the cortical layer. There is thus periosteal, exceedingly dense new bone formation, which without clear demarcation fuses partly into the profound, normal stratum of the cortical bone, and partly, in the longitudinal direction of the bone, into the adjacent normal osseous tissue. However, the layer of new bone is made conspicuous not only by its eburneous structure with very narrow Haversian canals, but also by some few more dense zones or layers of calcification parallel with the surface, and by the generally indistinct lamination: particularly around the vascular canals, etc. the lamellae fail show regular, concentric arrangement, being more or less straightened. There are scarcely any other remarkable structural details, which might be added to the description. There is no trace of inflammation, and tumour formation can be ruled out. The pathogenesis and aetiology of the change is quite obscure.

Summary of the Cases

We are thus confronted with a group of six siblings, four of whom with diaphyseal osteosclerosis and hyperostosis in one or more, up to four, of the long bones. There is a certain tendency towards symmetrical involvement, but this is not regularly present. The age at which the

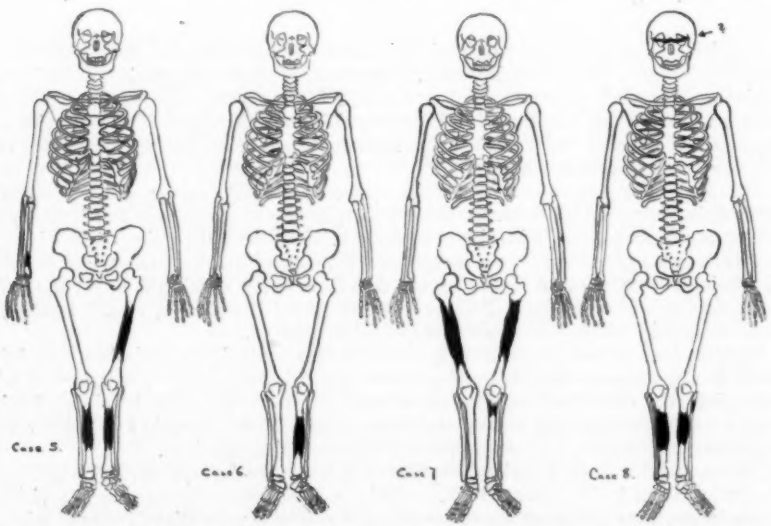


Fig. 12. The distribution of the diaphyseal changes in the four cases.

disturbance developed could not be established, but pain, presumably corresponding to the onset of the disease, commenced approximately on or after pubescence. The changes advance very slowly for a number of years, but seem subsequently to become stationary.

Signs of systemic involvement were not disclosed by my examinations: chronic anaemia, enlargement of the spleen, and endocrinous stigmata were absent. Every one of the four subjects affected presents a normal, harmonic appearance as regards the shape of the body, normal sexual development, and entirely satisfactory intelligence. The histories do not reveal any febrile conditions or other indications of systemic disease paralleling the onset of the symptoms. Diaphyseal sclerosis may develop quite insidiously, so that the patient fails to notice it. On the other hand, there may be boring, deep pain in the leg (especially below the knee), which by the patients themselves is compared with toothache, and which remains for a couple of years (apparently for the period during which the lesions advance). Neither the pain nor the sclerosis are necessarily involving all the bones affected at the same time.

Since I was incapable of finding in the literature any cases completely tallying with my own, I felt that these (presumably together with Feddema's cases) represent a clinical entity, which I name, »hereditary, multiple, diaphyseal sclerosis».

Discussion

Concerning differential diagnosis as against similar conditions the following should be pointed out:

In CAMURATI's case of »symmetrical hereditary osteitis» the disease developed earlier in life, the involvement being more extensive over the entire skeleton. The same applies to ENGELMANN's and SEAR's cases, which in addition are isolated cases without data as to hereditary occurrence. FRITSCH's case resembles my own in many details, but there was more skeletal involvement, and the condition was associated with well-marked anaemia. Even in that case no data were given as to hereditary occurrence. It is far from certain that the lack of data as to heredity or a statement to the effect that similar cases are unknown in the family, is actual evidence in disfavour of a hereditary disturbance. It may be a question of small families or solitary persons without closer relations. The investigator may also have contented himself with asking about the hereditary conditions. Repeated experience has convinced me that this is an altogether unsatisfactory procedure: in order to detect a hereditary disturbance one has to seek out the siblings and relations of one's patient — at least when dealing with a condition, which does not produce very striking external symptoms.

The differentiation from NEUHAUSER's *et al.* cases is obvious: those cases present (radiologically and microscopically) a combination of new bone formation and bone absorption with progressive change from the former to the latter. My cases, however, represent pure new bone formation.

Other conditions which might be mentioned in this connection are, Albers-Schönberg's marble-bone disease, Albright's fibrous dysplasia of bones, Caffey & Silvermann's infantile cortical hyperostoses, and Jaffe's osteoid-osteoma. From those diseases my cases differ conspicuously by the patho-anatomical picture, onset and involvement.

SUMMARY

The writer describes diaphyseal sclerosis and hyperostosis affecting some few (1—4) long bones in four siblings. The condition does not seem to have been known previously.

ZUSAMMENFASSUNG

Verf. beschreibt eine Diaphysensklerose und -hyperostose in einigen wenigen (1—4) Röhrenknochen bei vier Geschwistern. Die Krankheit scheint bisher nicht bekannt zu sein.

RÉSUMÉ

L'auteur décrit une sclérose et hyperostose diaphysaire au niveau de quelques os longs (1 à 4) chez quatre frères et sœurs. L'affection semble inconnue jusqu'ici.

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